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AN ECONOMIC ANALYSIS OF RESTRUCTURING UNDERGRADUATE HELICOPTER FLIGHT TRAINING

by

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March 1999

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The U.S. Navy helicopter fleet is undergoing an unparalleled reduction in the number of different types of helicopters flown. All of the helicopters flown in the Navy are being reduced to two variants; the CH-60S and the SH-60R. A determination of the best way to train the pilots of these two new airframes is desired. Four different training alternatives are developed, specifying various rates of student throughput and various combinations of training aircraft. Each of these alternatives is then applied to two different training plans, which consider the consolidation of different levels of flight training. Aircraft cost data and student throughput requirements are determined through analysis of Navy Visibility and Management of Operating and Support Costs (VAMOSC) data and historical annual training requirements, respectively. Aircraft procurement and operating costs for each alternative are estimated. A ranking of some important benefits of the different alternatives are developed and a complete cost-benefit analysis is conducted. An Additive Weighting and Scaling model, along with a Hierarchical Multi-attribute model are used to evaluate the resulting alternatives. The results of this study indicate that under most circumstances the preferred alternative tends to be the one in which the Navy maintains the current training organization.

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AN ECONOMIC ANALYSIS OF RESTRUCTURING UNDERGRADUATE HELICOPTER FLIGHT TRAINING

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ABSTRACT

The U.S. Navy helicopter fleet is undergoing an unparalleled reduction in the number of different types of helicopters flown. All of the helicopters flown in the Navy are being reduced to two variants; the CH-60S and the SH-60R. A determination of the best way to train the pilots of these two new airframes is desired. Four different training alternatives are developed, specifying various rates of student throughput and various combinations of training aircraft. Each of these alternatives is then applied to two different training plans, which consider the consolidation of different levels of flight training. Aircraft cost data and student throughput requirements are determined through analysis of Navy Visibility and Management of Operating and Support Costs (VAMOSC) data and historical annual training requirements, respectively. Aircraft procurement and operating costs for each alternative are estimated. A ranking of some important benefits of the different alternatives are developed and a complete cost-benefit analysis is conducted. An Additive Weighting and Scaling model, along with a Hierarchical Multi-attribute model are used to evaluate the resulting alternatives. The results of this study indicate that under most circumstances the preferred alternative tends to be the one in which the Navy maintains the current training organization.

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EXECUTIVE SUMMARY

In an effort to streamline the helicopter force, the U.S. Navy is implementing the Helicopter Master Plan (HMP). Beginning in the spring of 2000, this plan will reduce the number of different types of helicopters flown by the U.S. Navy to only two: the CH-60S and the SH-60R. The savings in time and money resulting from the restructuring of the helicopter fleet suggest that possible savings may result from restructuring the helicopter training pipeline as well.

This thesis suggests four potential training options. Each option describes a different training squadron organization. These four options are further broken down into two distinct plans. These two plans address whether advanced undergraduate flight training should be conducted in the TH-57C or the H-60. This breakdown results in eight training alternatives for analysis.

Each of the training alternatives is analyzed to determine costs and benefits. Costs are broken down into procurement costs and operating costs. Procurement costs reflect those costs associated with purchasing the number of helicopters required for each option. Operating costs are estimated using historical costs per flight hour from the Navy's Visibility and Management of Operating and Support Costs (VAMOSC) database. These costs are then used to determine annual operating costs for each option.

Four main benefits are considered for each alternative. These benefits are quality, number of squadrons decommissioned, number of squadrons commissioned, and command opportunity. Each alternative receives raw scores in each of these benefit categories. The decision-maker then weighs the benefits as he or she desires. The costs and benefit scores are then analyzed to determine the preferred training alternative.

Two methods are used to determine the preferred training alternative. The first is an Additive Weighting and Scaling model and the second is a Hierarchical Multi-attribute decision model. The first model provides the decision-maker with a cost-benefit ratio and the second allows the user to weigh the importance of cost against benefits. These methods allow the decision-maker to alter the relative weights of the benefits and cost to determine the preferred training alternative.

Sensitivity analysis is then performed on three primary inputs. The analysis, in most cases, calls for the training squadron organization to remain unchanged.

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I. INTRODUCTION

A. PROBLEM DEFINITION

In an effort to streamline the U.S. Navy's helicopter fleet, the Helicopter Master Plan (HMP) was developed. The Helicopter Master Plan calls for all fleet helicopters in the Navy's inventory to be combined into two variants, the SH-60R and the CH-60S. The SH-60R will assume the roles previously held by the SH-60B and the SH-60F, while the CH-60S will assume the roles of all other current Navy fleet helicopter platforms. The reduction in the number of different types of helicopters flown by the Navy suggests that a reduction in the number of advanced training squadrons may be prudent as well. Re-structuring has the potential to improve efficiency, increase proficiency and capture savings in both time and training costs. The implementation of the Helicopter Master Plan provides a unique opportunity to re-evaluate the training of Navy helicopter pilots and perhaps institute some changes in the training pipeline.

Currently, the SH-60R and CH-60S platforms are scheduled for introduction into the fleet in the middle of the year 2000. Yet, the Navy has no specific plan for the training pipeline of the CH-60S and SH-60R. This study will develop four feasible training alternatives, each of which has two distinct training formats, and will analyze each of the resulting eight alternatives in terms of their costs and benefits.

The two training formats classify the way advanced flight training will be conducted. The first format is the one currently employed. In the current system, students conduct basic training in the TH-57B/C helicopter, earn their wings, then proceed to a Fleet Replacement Squadron (FRS) for fleet and tactical training in their ultimate fleet helicopter. The second format is new. It considers combining advanced undergraduate helicopter training with FRS familiarization training, using actual fleet aircraft, thereby eliminating an entire level of flight training.

Conducting undergraduate helicopter training in the TH-57 has been an extremely efficient process. The TH-57 aircraft is economical to operate, maintenance is contracted from a civilian operator, and given the diverse number of helicopters that the Navy

operates in the fleet there were no savings to be garnered by doing it differently. However, with the reduction in Navy helicopters to a single model, the H-60, changing the way training is conducted may prove prudent. Currently, upon earning their wings, Navy helicopter pilots are well-trained to fly an aircraft that is only flown as a trainer. Student pilots learn the basics of helicopter flight in primary helicopter training where the economies of operation, ease of repair and simplicity of the TH-57 flight systems still make sense. However, continuing to train for another 90 flight hours in an aircraft whose flight characteristics are far removed from any fleet operational aircraft may be questionable.

The goal of this thesis is to develop and produce, via a cost-benefit analysis, a quantifiable measure of the worth of each of the eight alternatives. The results will be used by senior Navy leadership to decide the appropriate course of action for future helicopter training.

B. U.S. NAVY HELICOPTER TRAINING ORGANIZATION

1. Training

Currently, student naval aviators selected to train as helicopter pilots complete both a primary and an advanced helicopter syllabus in the TH-57B/C at Whiting Field in Milton, Florida. Primary helicopter training focuses on basic aircraft familiarization while the advanced syllabus teaches airways and instrument navigation and an introduction to fleet operations (shipboard landing, external cargo, formation flight, etc.). Upon the successful completion of this training, pilots are designated as Naval Aviators and proceed to their respective Fleet Replacement Squadron (FRS).

2. Fleet Replacement Squadron

Following designation, pilots are ordered to an FRS to undergo training in their designated fleet aircraft. These "nugget" aviators arrive at the FRS with anywhere from 190 to 240 flight hours, approximately half of which are in helicopters. Most fleet

helicopter types also have a Weapons Training Unit (WTU), which is responsible for follow-on tactical and mission specific training.

The FRS introduces pilots to basic airmanship skills in their fleet helicopter. A host of different flight maneuvers and techniques are taught and mastered during this stage. Once a student has displayed mastery of aircraft systems, emergency procedures and airmanship skills, the student undergoes a Naval Air Training and Operating Procedures Standardization (NATOPS) check flight. Successful completion of the NATOPS check signifies a readiness to proceed to tactical and mission training.

C. HELICOPTER MASTER PLAN

The purpose of the Helicopter Master Plan, or HMP, is to streamline the U.S. Navy's helicopter fleet. Figure 1 shows the timeline for this plan. The SH-60F and SH-60B missions will be passed to the SH-60R variant. Also note the collection of several missions under the CH-60S. The Anti-Mine Counter Measure (AMCM) mission, currently performed by the MH-53, will be tested using the CH-60S in the Spring of 1999 to determine whether or not the CH-60S is capable of performing this mission.

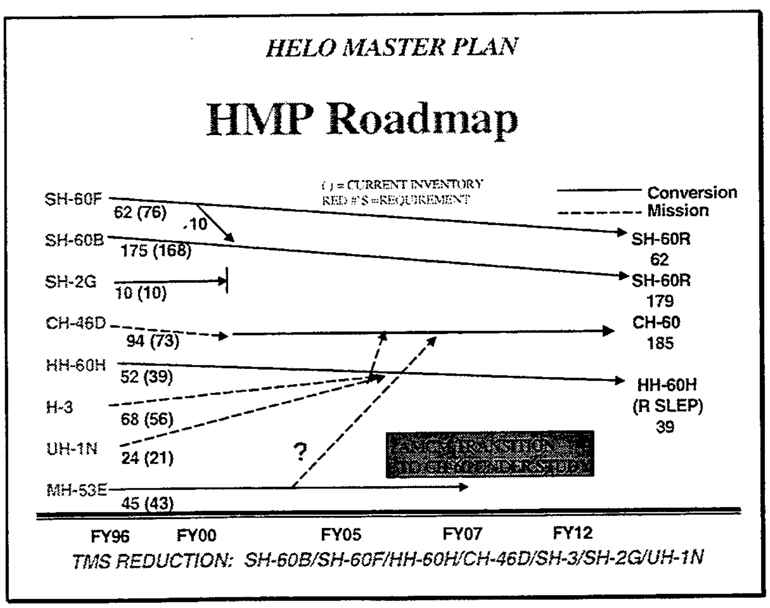

Figure 1: Schedule of Implementation for the Helicopter Master Plan

II. DESCRIPTION OF ALTERNATIVES

A. INTRODUCTION

The imminent implementation of the Helicopter Master Plan into fleet operations motivated this study of possible training alternatives. Four main options are studied, each of which is further broken down into two distinct plans. Together, these options and plans comprise eight different alternatives for study. The plans, referred to as 'Plan A' or 'Plan B', specify how advanced helicopter flight training should be conducted. Plan A assumes that students fly the TH-57B in primary helicopter flight training, followed by the TH-57C in advanced flight training, receive their wings, then proceed to an appropriate FRS for training in their respective fleet helicopter. Plan B proposes that advanced flight training be combined with the FRS to become one training stage so that students are introduced sooner to their ultimate fleet helicopter. Specifically, in Plan B, students proceed directly from primary flight training in the TH-57B to the FRS for advanced flight training in their fleet helicopter, bypassing the TH-57C.

B. DESCRIPTION OF OPTIONS

1. Option I

This option, depicted in Figure 2, maintains the existing squadron organization while replacing the existing helicopters with either the CH-60S or SH-60R, as appropriate. This option assumes the MH-53 mission could not be performed by the CH-60S, therefore the MH-53 remains a viable aircraft. The resulting naval helicopter fleet consists of the CH-60S, SH-60R and MH-53.

In this option, the HSL and HC communities employ the SH-60R and CH-60S, respectively, for all phases of their respective training pipelines. The HS squadrons, by contrast, train in the SH-60R for the majority of their FRS basic and tactical training, and then train in the CH-60S platform for CH-60S specific mission training such as Combat Search and Rescue (CSAR) and Vertical Replenishment (VERTREP).

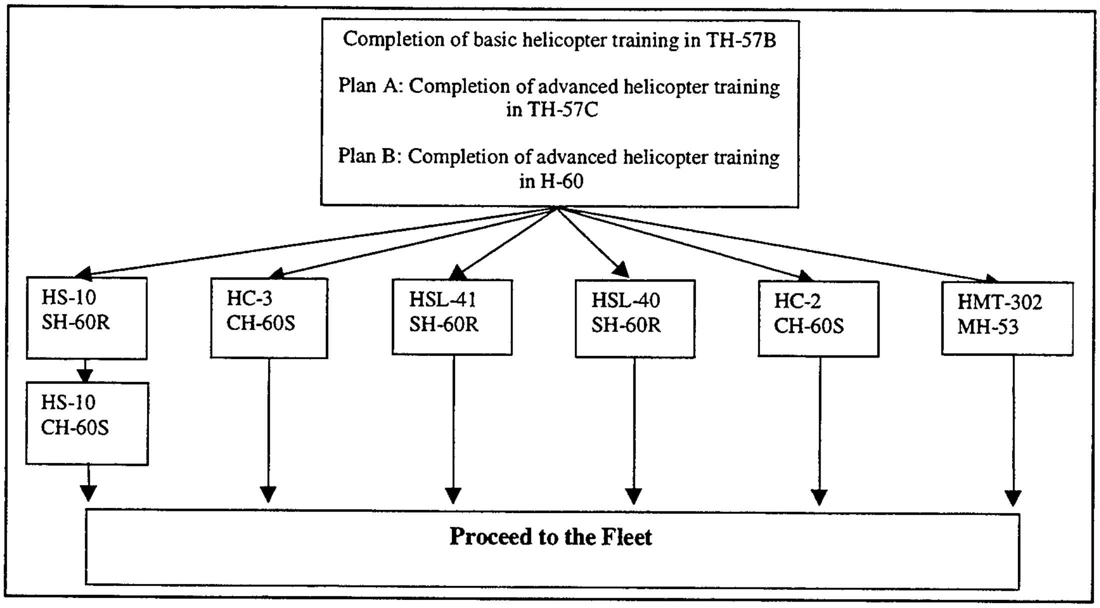

Figure 2: Option I Squadron Organization

2. Option II

This option, depicted in Figure 3, is identical to option I except that it is assumed the MH-53 mission can be performed by the CH-60S; therefore the MH-53 is replaced by the CH-60S. The resulting helicopter inventory consists solely of SH-60R and CH-60S helicopters.

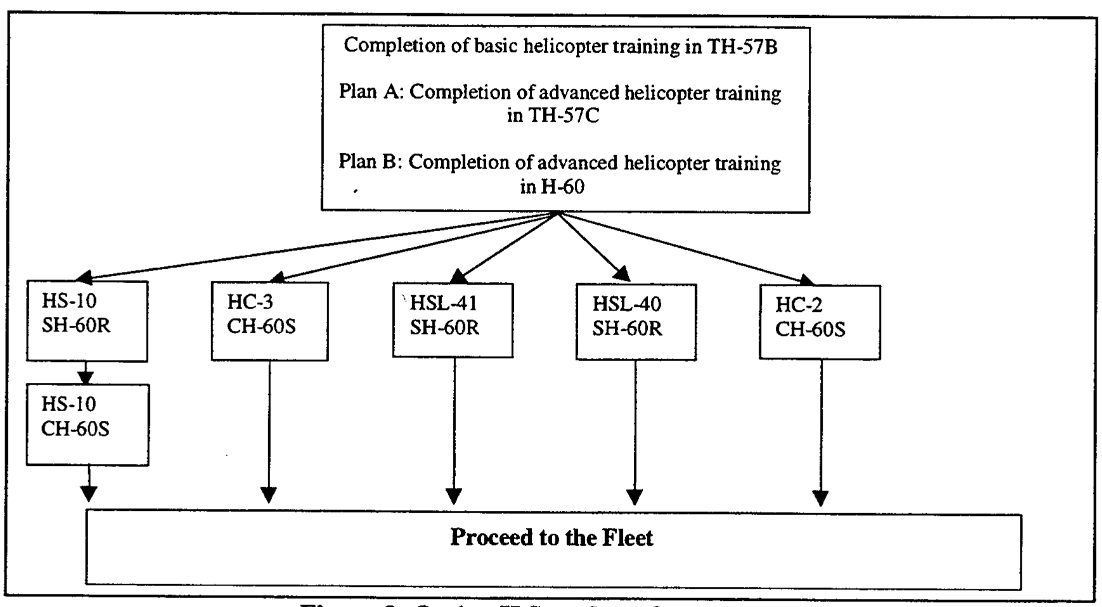

Figure 3: Option II Squadron Organization

3. Option III

This option, depicted in Figure 4, is the first significant deviation from the status quo. The resulting squadron makeup would consist of one CH-60S FRS, one SH-60R FRS, one CH-60S WTU, and one SH-60R WTU on each coast, for a total of eight H-60 training squadrons. The FRS would be responsible for training the pilot through his/her NATOPS check. The WTU would be responsible for follow-on training in tactics and mission specific functions.

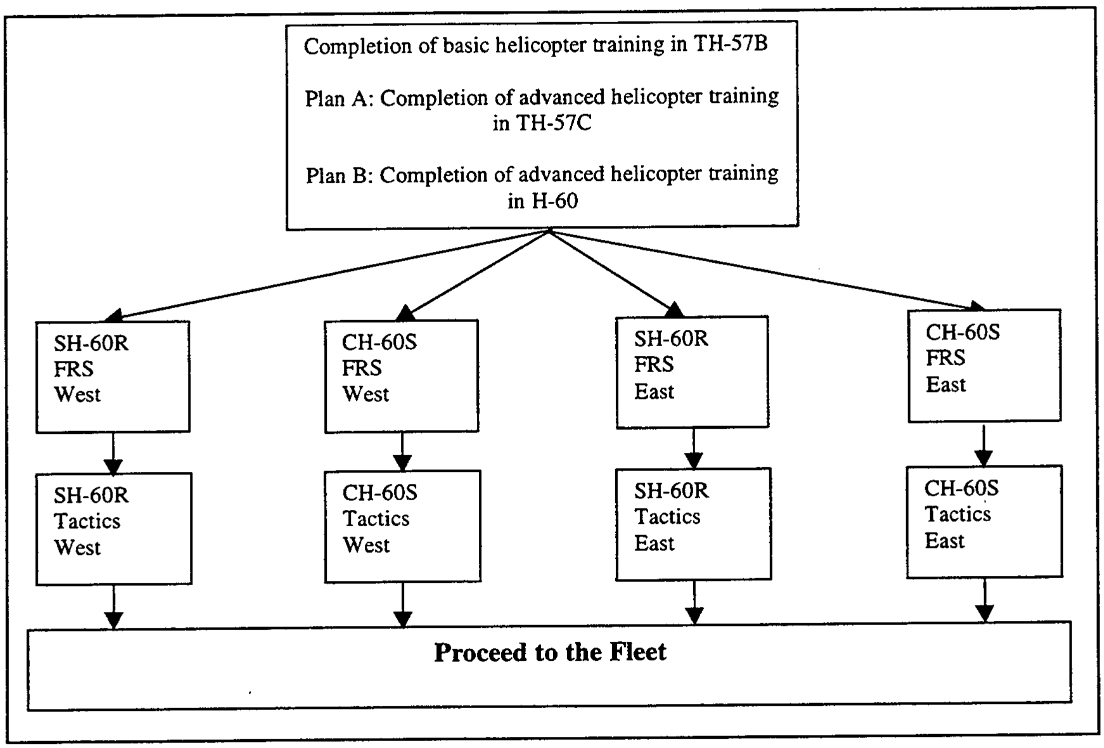

Figure 4: Option III Squadron Organization

4. Option IV

Option IV presents the most radical departure from the current training concept and is depicted in Figure 5. This option has one joint FRS and two WTU's on each coast, for a total of six squadrons. The joint FRS would conduct training in the CH-60S through the NATOPS check. Again, the WTU would be responsible for follow-on training in tactics and mission specific functions.

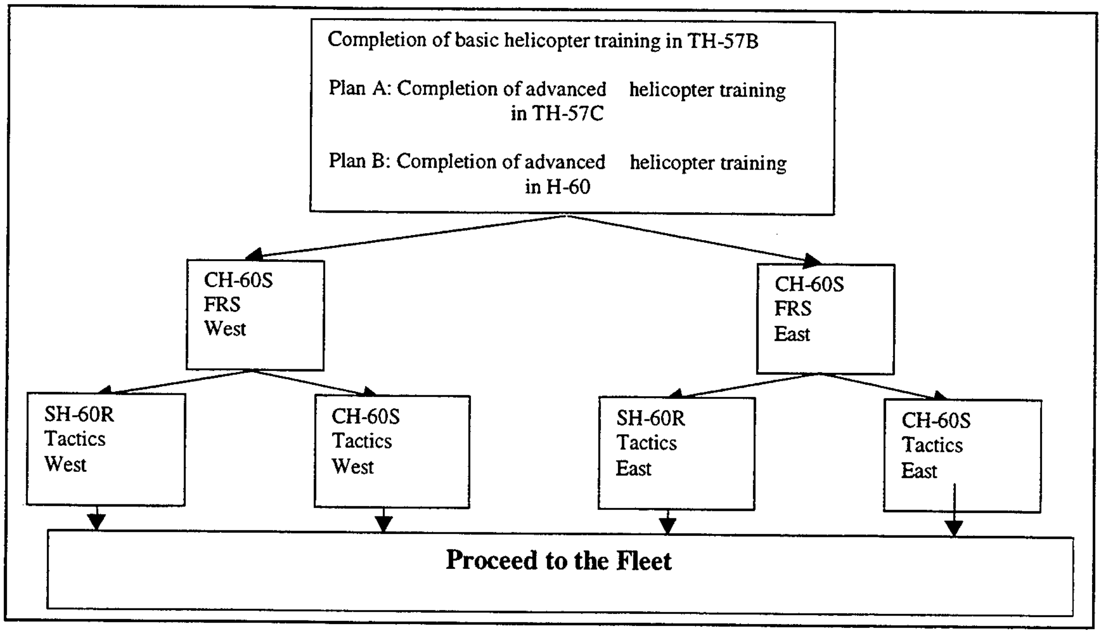

Figure 5: Option IV Squadron Organization

C. DESCRIPTION OF PLANS

Each of the four options described previously is further broken out into one of two training plans that specify how undergraduate helicopter training should be conducted.

1. Plan A

Plan A may be viewed as maintaining the current undergraduate helicopter training method. Under this method, students first learn to fly the TH-57B helicopter. This stage teaches basic airmanship skills and helicopter maneuvers. Historically, students gain approximately 40 hours of flight time during this stage of flight training. At the conclusion of this stage, students are capable and confident in their knowledge of aircraft systems, emergency procedures and their physical ability to fly the helicopter. Following this familiarization stage in the TH-57B, students then proceed to advanced training in the TH-57C for instruction in the more challenging world of instrument flight.

This advanced stage of flight training is considerably more difficult than the earlier basic familiarization stage flown in the TH-57B. Consisting of approximately 90 hours of flight time, this stage teaches students the nuances of instrument flight. The act

of physically flying the helicopter becomes less difficult and more instinctive and thinking about other issues, such as navigation, emergencies, or tactical decision making, becomes the primary mental concern. At the conclusion of this stage of flight training, students receive their wings, and become designated as naval aviators. After designation, students proceed to their respective FRS for their initial exposure to their fleet aircraft. Plan A assumes that the newly designated pilot awaiting FRS training received primary training in the TH-57B and advanced training in the TH-57C, as described.

2. Plan B

Plan B combines the advanced stage of helicopter flight training, currently flown in the TH-57C, with training in the FRS. In this scenario, students receive their introduction to helicopter instruction in the TH-57B, just as described in Plan A. Students emerge from this stage with approximately 40 hours of helicopter flight time and are well skilled in basic helicopter handling and systems knowledge. However, at this point in the training pipeline, Plan B sends the students to a different stage, designed to combine the training found in advanced helicopter training with that found in the FRS.

This advanced stage, which was flown in the TH-57C in Plan A, is now flown in the CH-60S or SH-60R. The students start this stage with classroom instruction in the systems and characteristics of this new helicopter. The B and C variants of the TH-57 are so closely related that this instruction is not required in Plan A. Following this instruction, the H-60 students learn to fly the same maneuvers previously learned in the TH-57B. Upon mastery of basic piloting skills in the fleet aircraft, the students then enter the instrument flight training syllabus. Figure 6 shows the differences between the two plans.

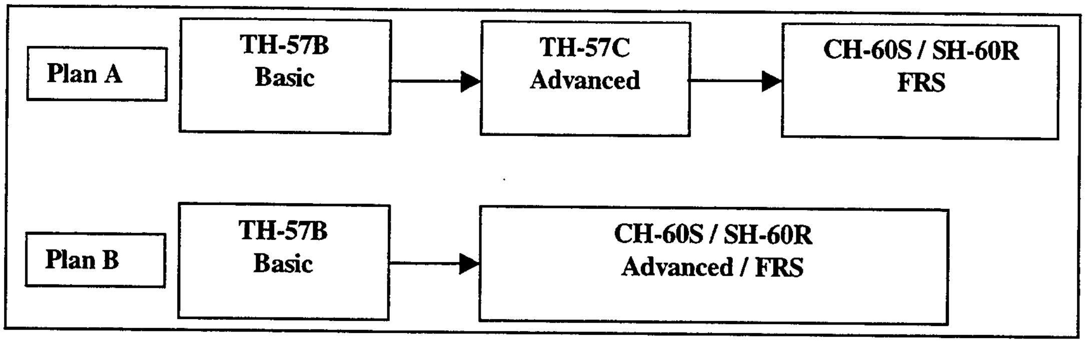

Figure 6: Depiction of Plans A and B

D. ASSUMPTIONS

Development of these eight models requires some fundamental assumptions regarding student throughput and syllabus characteristics. These two areas are critical in the creation of any training plan and therefore warrant sensitivity analysis, which is addressed in a later chapter.

The models use student throughput levels provided by N889 for fiscal year 1999. These levels are assumed to remain constant and are shown in Table 1 (Mullarky 1998).

FY99 Requirements			
Aircraft	Coast	Annual Fills	
		Junior Officer	Department Head
H-60B	East	62	40
H-60B	West	63	40
H-60F	West	47	16
H-3	East	14	5
H-46	West	64	16
H-53	East	23	6

Table 1: Projected FY99 Student Requirements By Helicopter Community

Students are classified at the FRS level by categories, which range from I to V. A category I student requires the full syllabus and exposure to every training area. Categories II through V represent decreasing requirements of the full syllabus. Most of the students in these categories have prior fleet experience and are in the training pipeline to upgrade to the more modern H-60 or simply to re-qualify after a non-flying duty

assignment. In either case, category II through V students require a fraction of the syllabus that a category I, or CAT I, student requires. Historically, this fraction is 0.8. In other words, the training flight hours required for a CAT II, III, IV, or V student is 80% that of a CAT I student. Therefore, CAT I equivalence is obtained by summing the CAT I students and 80% of the CAT II through V students. The values shown in Table 1 are standardized into units of 'CAT I equivalent'. Options III and IV are unique, however, and require additional computation to determine CAT I equivalence.

In options I and II the FRS provides both basic fleet aircraft training and mission / tactical training. However, options III and IV separate the FRS into two squadrons: the FRS, responsible for introduction to the H-60 and systems training, and the WTU, responsible for training mission skills. This division is effective for training those pilots who fly only the CH-60S or the SH-60R, but not both. However, the HS community is expected to operate both the CH-60S and the SH-60R. This dual helicopter community requires extra training to ensure proficiency in both the CH-60S and SH-60R platforms.

HS helicopter pilots will conduct the FRS and Tactics training using the SH-60R. However, to conduct training in the CSAR mission area, they also require some time in the CH-60S Tactics squadron. Consequently, HS pilots in options III and IV conduct training in the SH-60R FRS, SH-60R Tactics, and a portion of CH-60S Tactics. CSAR training flights for the HS pilots account for approximately 55% of the syllabus provided by a CH-60S Tactics squadron. This additional training requirement is factored into the CAT I equivalence calculation for the CH-60S Tactics squadrons in alternatives III and IV. In summary, the student throughput is normalized to more accurately reflect actual aircraft usage.

III. COST ANALYSIS

A. BACKGROUND

The cost estimate for each alternative consists of two parts; procurement costs and 20 years of annual training costs. Procurement costs involve the actual purchase of new helicopters needed for each alternative. The unit procurement costs of the SH-60R and CH-60S are assumed to remain constant at $19.0M and $13.6M, respectively. All costs are in constant 1997 dollars (FY97$). Annual training costs, in this case, represent the cost of training the projected FY99 pilot requirements.

B. ANNUAL TRAINING COSTS

The annual costs for the eight alternatives are based on flight hours. Annual costs are determined by first estimating the average number of flight hours needed in each platform, then multiplying by the historical average cost per flight hour for each platform. The annual totals represent an estimate of the cost to train the indicated number of students through the appropriate phases of flight training.

The projected number of students expected in each helicopter community in FY99, shown in Table 1, are combined with the expected number of flight hours required for each phase of training to calculate the total number of flight hours expected. Multiplying by the estimated cost per flight hour gives an estimate of the annual cost for each alternative.

The cost per flight hour of each type of helicopter is one of the most important characteristics to consider in a cost analysis. These values vary greatly between aircraft types. The estimates used in this thesis were developed using Navy VAMOSC[1] data from FY92 through FY97 (Naval Center for Cost Analysis, 1998). VAMOSC data is broken down into six mutually exclusive cost categories, as follows:

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[1] The "Visibility and Management of Operating and Support Costs" (VAMOSC) database

1.0 **Organizational Costs**: Those costs that are attributable to organizational level operations and maintenance support of regular operating aircraft.

2.0 **Intermediate Costs**: Those costs attributable to intermediate level operations and maintenance support.

3.0 **Depot Support Costs**: Those costs attributable to organic depot level maintenance activities and by commercial depot organizations.

4.0 **Training Support Costs**: Includes organizational costs of Fleet Readiness Squadrons, maintenance training, and specialty training.

5.0 **Recurring Investment Costs**: The cost of recurring investment items directly attributable to the various T/M/S. This includes the annual cost of purchases for modification kits and spares required for specific T/M/S aircraft.

6.0 **Other Functions**: These are the costs directly attributable to an aircraft T/M/S but not included elsewhere in the report. These include engineering or technical services support and costs of updating publications.

Six years worth of operating and support costs for each type aircraft were calculated from the historical data. This total was then divided by the total number of flight hours flown by that type aircraft in that six-year period. The resulting values represent the average cost per flight hour of that particular type aircraft over that six-year time span. These values are shown in Table 2.

Type Aircraft	VAMOSC 92-97 (CY97$)
H-1	4087
TH-57B	660
TH-57C	577
H-3	5949
CH-46D	4632
CH-46E	4828
HH-46D	5196
MH-53	7119
SH-60B	3745
SH-60F	4906
HH-60H	3553

Table 2: VAMOSC '92-'97 Costs per Flight Hour for Various T/M/S Helicopters

The cost per flight hour of the CH-60 helicopter is estimated in this study to be equal to that of the HH-60H, due to similarities in airframe, components, and mission. Similarly, the cost per flight hour of the SH-60R is estimated to equal that of the SH-60B, again due to similarities in construction, avionics, and mission.

A histogram of the expected annual costs of each alternative is shown in Figure 7. Notice that Plan B is generally more expensive than Plan A because more training time is spent in the H-60 vice the less expensive TH-57C.

Recall that in Plan B, advanced flight training is performed in the H-60 vice the TH-57C, so while Plan B yields an expected savings in training time, it ends up being more expensive than plan A in every alternative considered. This is because the operating costs of the TH-57C are much less than those associated with the H-60. So, any reduction in the number of training hours achieved by using the H-60 vice the TH-57C is quickly overwhelmed by the substantial increase in cost per flight hour.

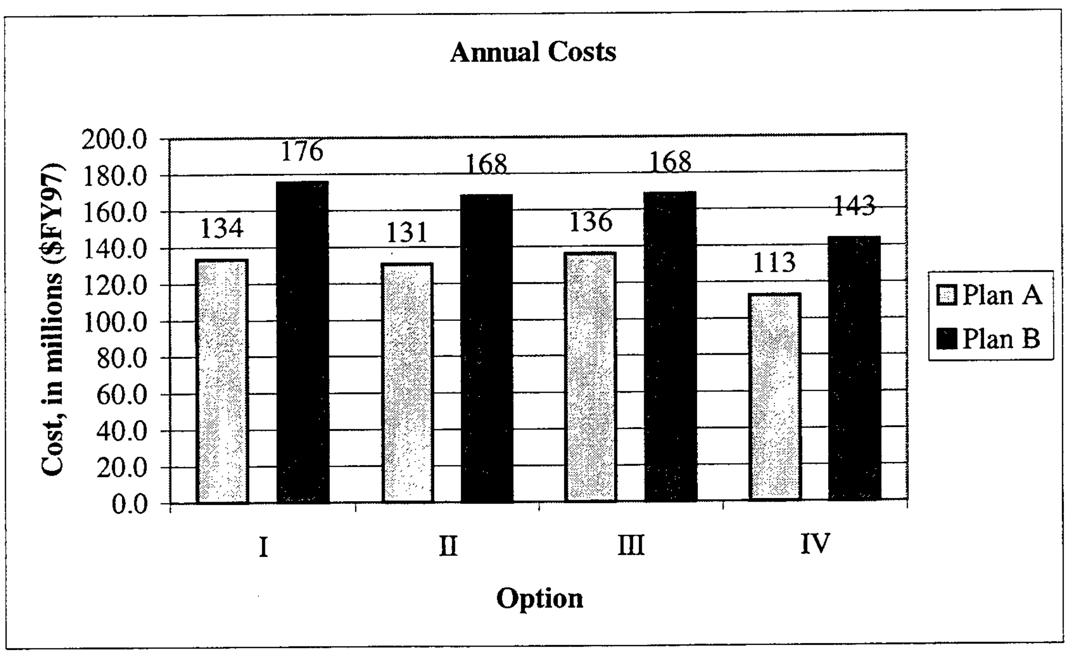

Figure 7: Annual Costs for each alternative, FY97$M

C. AIRCRAFT PROCUREMENT COSTS

The procurement costs are the most significant costs encountered in this study. The number of helicopters required for each alternative were determined using a methodology presented by the FRS Production Planning Factors conference at BUPERS during the summer of 1998. This methodology is discussed in detail in Appendix B. Three characteristics are primarily responsible for variations in the number of new aircraft required. These are syllabus length, number of sorties requiring fully mission capable (FMC) versus mission capable (MC) aircraft, and historic FMC and MC rates, which are indicative of maintenance reliability.

It is important to note that the procurement aspect of this problem is the most sensitive and has the greatest impact on the results. A slight change in any of the three major assumptions described above may affect the subsequent number of aircraft required. The unit costs for the SH-60R and CH-60S, provided by the Program Office, are approximately $19.0M and $13.6M, respectively (Mullarky 1998). Combined with these costs, small changes in the assumptions can add up to substantial cost differentials.

It is assumed that SH-60R and CH-60S helicopters are equally available. The total number of helicopters required for each training alternative is shown in Table 3. Figure 8 shows a comparison of the expected procurement costs required for each alternative.

Number of Helicopters	Alternative							
	IA	IB	IIA	IIB	IIIA	IIIB	IVA	IVB
SH-60R	45	54	45	54	54	67	32	32
CH-60S	19	25	23	31	26	34	48	68
Total	64	79	68	85	80	101	80	100

Table 3: Total Number of Each H-60 Variant Required in each Alternative

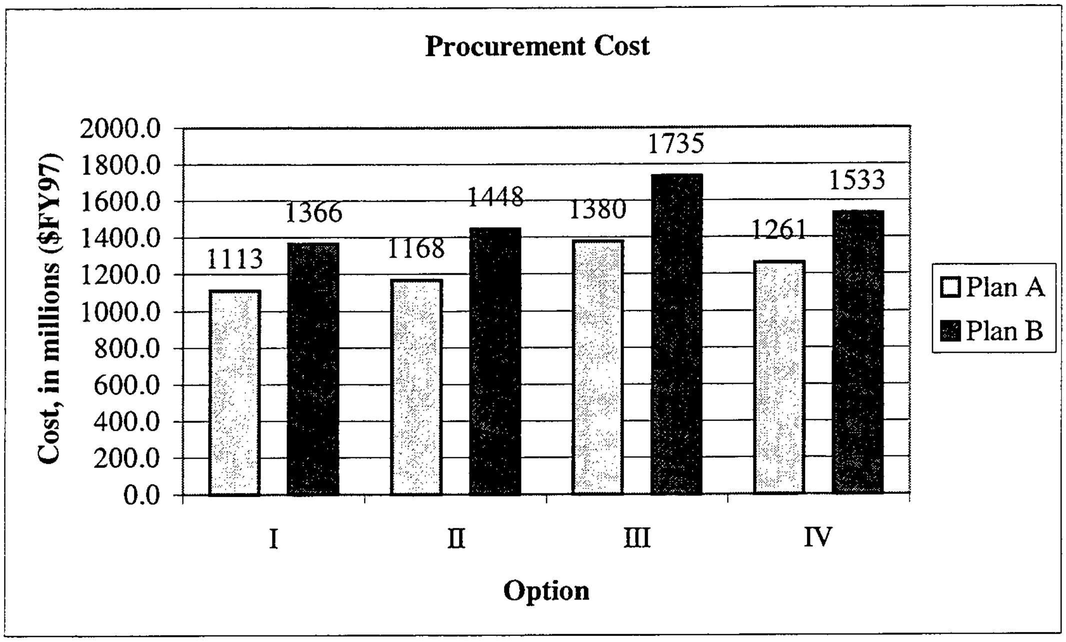

Figure 8: Aircraft Procurement Costs, FY97$M

D. TOTAL COSTS

Pricing out the alternatives for the next 20 years, applying a real discount rate of 3.5%, taken from the OMB Circular A-94, yields some interesting results. The discounted total cost shown at the top of each column in Figure 9 shows the amount of money, in FY97 millions of dollars, that would be required *today* to "buy" that alternative including procurement and annual training costs (Thompson 1992). A more detailed breakdown of the discounted total cost of each alternative is given in Appendix F. If cost were the Navy's only concern, the alternative with the lowest discounted total cost should be chosen. However, the discounted total cost of Plan A differs little between alternatives. The decision, therefore, should be based upon a combination of the discounted total cost and a measure of the benefits of each alternative.

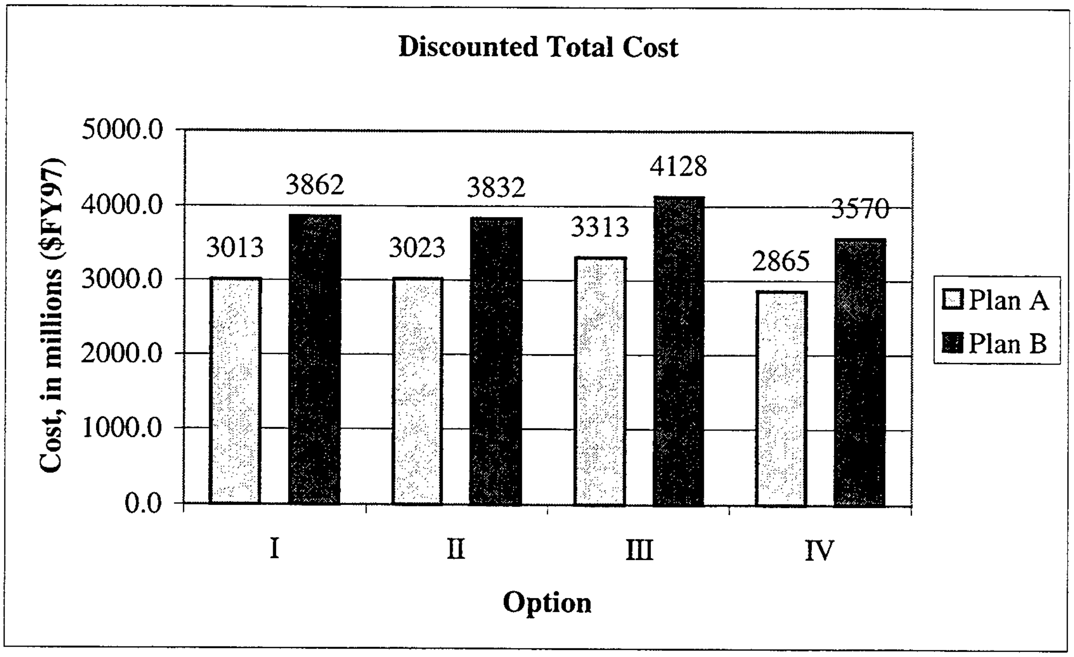

Figure 9: Discounted total cost, in FY97$M

IV. BENEFIT ANALYSIS

A. METHODOLOGY

Benefits may be described as the expected non-monetary results from an investment or the output resulting from a given input. Benefits may be either qualitative or quantitative in nature. Analysis of benefits provides a clear, well-defined, useful tool in the decision making process.

Identifying the potential benefits in restructuring undergraduate helicopter flight training is quite challenging. Benefits are somewhat subjective due to individual biases and priorities. The benefits selected for analysis in this study contribute directly or indirectly to the effectiveness of training helicopter pilots. They are *quality, implementation*, and *command opportunity.*

B. DEFINITION OF BENEFITS

1. Quality

Common sense dictates that the best way to improve flying skills is to fly. Students with more flight time in a given month should be more skilled and possess better situational awareness than pilots with fewer hours per month. Thus quality is measured by the average number of flight hours flown per month by a given student in each alternative.

Each alternative has a different student throughput, syllabus length in flight hours and syllabus length in months. These values are scaled using linear proportions within each alternative to determine the average number of hours flown per month per student. The raw scores for this benefit are shown in Table 4.

2. Implementation

The ease with which an alternative training method may be implemented is obviously quite important. As an indicator of the degree of difficulty in actualizing the given alternative, the number of squadrons that would need to be decommissioned or

commissioned is used. The pains associated with integrating a completely new aircraft are present in all of the different alternatives. However, some alternatives use more of the existing squadrons and the available infrastructure. Other alternatives require decommissioning some squadrons while concurrently commissioning others. Clearly, the former case is preferred over the latter.

The scores assigned to this benefit reflect the raw number of squadrons decommissioned or commissioned with each alternative and are shown in Table 4. A smaller value indicates less change from current squadron composition. Refer to Appendix E for specific squadron details within each alternative regarding status as commissioned or decommissioned.

3. Command Opportunity

Command opportunity also plays a role in evaluating the merit of each alternative. The raw scores of this benefit, shown in Table 4, represent the number of aviation commands that would be available. Obtaining command of an operational unit is a significant milestone in a naval officer's career, and weighs heavily in selection for promotion to the next senior rank. Therefore, in this benefit category, the bigger the number, the better the benefit.

Alternative	Quality	Number of Squadrons		Command Opportunity
		Decommissioned	Commissioned	
IA	9.288	0	0	8
IB	9.324	1	0	7
IIA	9.287	1	0	7
IIB	9.324	2	0	6
IIIA	8.224	2	4	9
IIIB	8.321	3	4	8
IVA	8.300	2	2	7
IVB	8.470	3	2	6

Table 4: Raw Benefit Scores for each Alternative

C. WEIGHTS

The priorities given each of these benefits are subjective by nature and will vary from one person to the next. The analysis conducted in this study allows the decision maker to vary the weights assigned to each of the benefits as he or she sees fit. As the weights of each of the benefits are varied, the respective effect of those benefits will be altered.

The weights are scaled such that their sum must be equal to one. In this fashion, the weights may be viewed as percentages. For example, a benefit being assigned a weight of 0.50 may be viewed as accounting for half of the total benefit given. This weighting scheme also allows for comparison between benefits.

If the benefit of Quality, for example, is twice as important as that of Command Opportunity, then that relationship should be evident in the respective weights assigned to each.

V. SELECTION OF ALTERNATIVES

A. ADDITIVE WEIGHTING AND SCALING

1. Definition

The first method applied to this problem is additive weighting and scaling (Army Logistics Management College, 1996). This method allows the decision-maker to weigh the benefits as he or she deems appropriate and determines a cost / benefit ratio for each alternative.

The beauty of this model is its simplicity. The benefits are scaled in such a manner that seemingly incomparable units become comparable. In addition, costs have no weight assigned to them, which eases the requirements on the decision-maker.

2. Application

Let the eight alternatives be represented by the subscript $j = 1, 2, \ldots, 8$. Let the four benefits be represented by $k = 1, \ldots, 4$. Let the raw score of a given benefit be indicated by r. Therefore, $r_{j,k}$ indicates the raw score of the j^{th} alternative for the k^{th} benefit. Further, let $r_{k\ best}$ indicate the best score for benefit k. Note that the best score does not necessarily mean the largest score. If a small value is preferred, then the best score would be the smallest, and vice versa. The raw scores for each attribute and alternative are scaled as follows:

If a high number is preferred in the raw score, then the following formula is applied to scale the data:

$$S_{j,k} = \frac{r_{j,k}}{r_{kbest}}$$

where $S_{j,k}$ = the scaled value of benefit k in alternative j

$r_{j,k}$ = the raw score

r_{kbest} = the 'best' score of benefit k over all alternatives

If a low number is preferred in the raw score, then the following formula is applied to scale the data:

$$S_{j,k} = \frac{r_{kbest}}{r_{j,k}}$$

where $S_{j,k}$ = the scaled value of benefit k in alternative j

$r_{j,k}$ = the raw score

r_{kbest} = the 'best' score of benefit k over all alternatives

These scaled scores now provide a numerical relationship between the benefits for each alternative. Obviously, all scaled scores fit into the interval [0,1]. The alternative with the best raw score for a given benefit will have a scaled score equal to 1 in that benefit. Let the weight assigned to benefit k be denoted w_k. The weighted score of benefit k in alternative j is determined by taking the product of $S_{j,k}$ and w_k.

$$WS_{j,k} = S_{j,k} * w_k$$

Where $WS_{j,k}$ = weighted score of benefit k in alternative j

$S_{j,k}$ = the scaled value of benefit k in alternative j

w_k = weighted score of benefit k

Let the overall benefit score for alternative j be denoted B_j. Then

$$B_j = \sum_k WS_{j,k}$$

The decision-maker may now draw conclusions based upon benefits alone, if he or she desires. If benefits were the only consideration, the alternative with the largest overall benefit score would be the preferred alternative.

The cost-benefit ratio is obtained for a given alternative by dividing the respective discounted total cost by the respective overall benefit score determined above. Let V_j represent the discounted total cost of alternative j. Then the cost-benefit ratio would be calculated as follows:

$$(\text{Cost-Benefit Ratio})_j = \frac{V_j}{B_j}$$

Since a small cost and large benefit are preferred, a small cost-benefit ratio is desired.

3. Results

Analysis of the Additive Weighting and Scaling method highlights many important relationships that exist between alternatives. Of particular importance are the relative rankings of the alternatives. Table 5 shows the discounted total cost of each alternative along with the scaled, normalized scores of each benefit for each alternative. Many conclusions may be drawn prior to applying weights to these scaled benefit scores.

Alt	Discounted total cost (FY97$M)	Quality	# of Sqdns:		Command Opportunity
			Decom	Comm	
IA	3013	0.996	1.000	1.000	0.889
IB	3862	1.000	0.500	1.000	0.778
IIA	3023	0.996	0.500	1.000	0.778
IIB	3832	1.000	0.333	1.000	0.667
IIIA	3313	0.882	0.333	0.200	1.000
IIIB	4128	0.892	0.250	0.200	0.889
IVA	2865	0.890	0.333	0.333	0.778
IVB	3570	0.908	0.250	0.333	0.667

Table 5: Costs and Scaled Benefit Scores for the Additive Weighting and Scaling Model

For example, the discounted total cost of each alternative plays a vital role in the determination of the cost-benefit ratio. Note that alternative IVA has the smallest discounted total cost, followed by alternative IA and IIA. These three alternatives deserve extra attention since the gap between them and the remaining five is significant. It is also worth noting that alternatives IA and IIA are very close in discounted total cost. Recall that the only difference between these two models is the small number of students who will train in the MH-53 helicopter in alternative IA and train in the CH-60 helicopter

in alternative IIA. Since flight hours and student throughput are the same, the difference is found in the cost per flight hour of the CH-60 versus the more expensive MH-53.

The ordinal rankings of the alternatives within each benefit category are also informative. Alternative IA achieves the highest score possible in two of the benefits: number of squadrons decommissioned and commissioned. Consequently, alternative IA has no rival if the decision-maker concerns themselves solely with the number of squadrons commissioned and/or decommissioned.

Figures 10 and 11 show the results of considering only the number of squadrons decommissioned or commissioned, respectively. In Figure 10, the benefit corresponding to the number of squadrons decommissioned is given a relative weight of 100 percent while the remaining benefits are given a relative weighting of zero percent. Note that Alternatives IA and IIA dominate the remaining training alternatives in Figure 10. In Figure 11, where the number of squadrons commissioned is given all of the relative weighting, alternative IA and IIA still outperform the other in terms of cost-benefit ratio. The improved cost-benefit ratio of alternatives IB and IIB is due to their excellent scores with respect to this benefit.

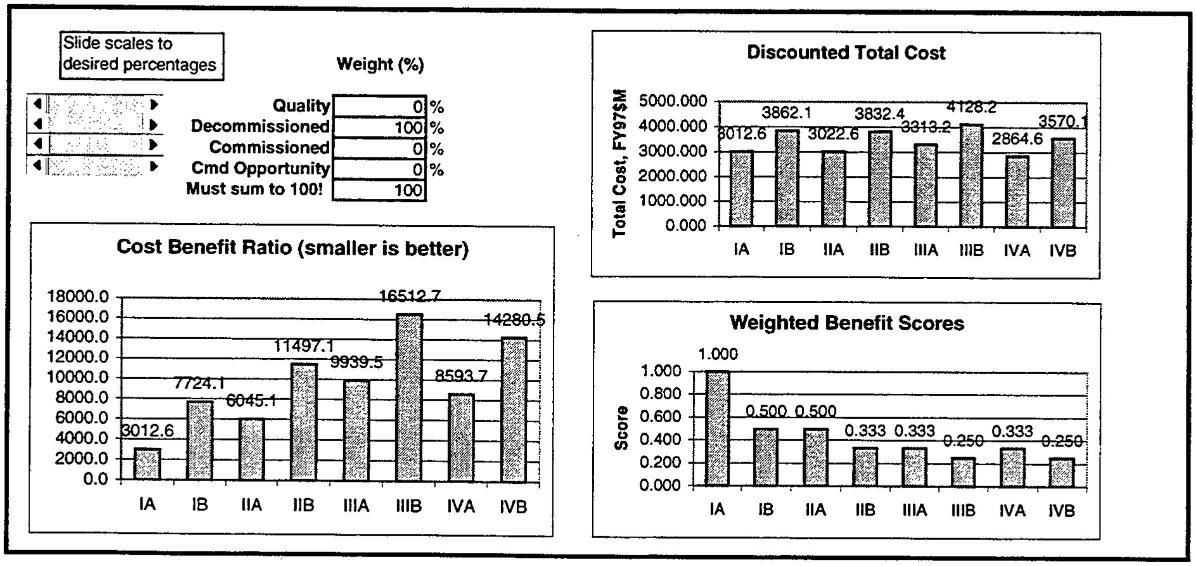

Figure 10: Additive Weighting and Scaling Model with Number of Squadrons Decommissioned as the only Benefit Considered

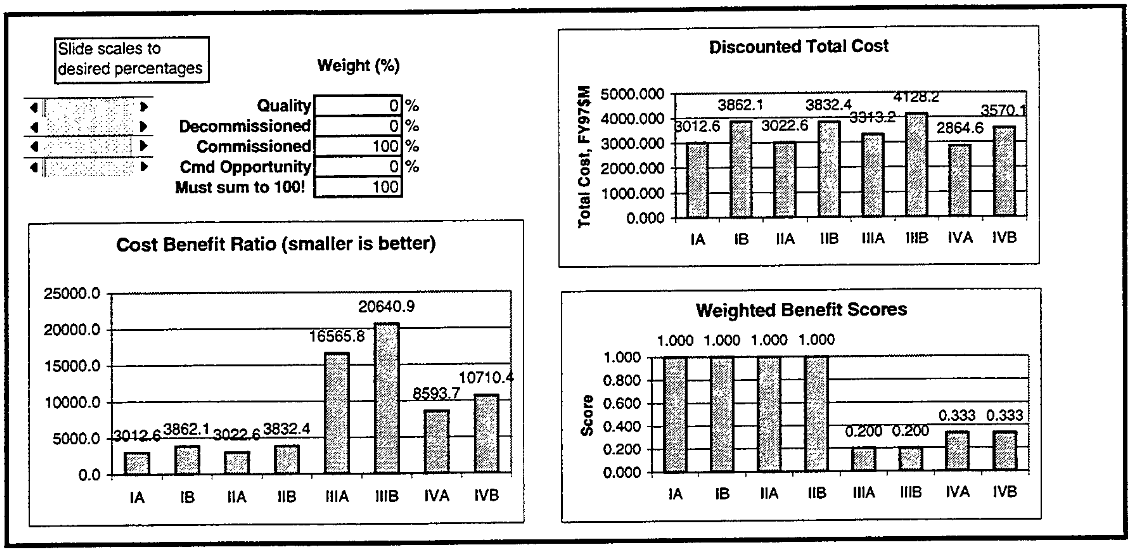

Figure 11: Additive Weighting and Scaling Model with Number of Squadrons Commissioned as the only Benefit Considered

Alternatives IA and IIA also maintain their dominance when considering quality alone. The best performers in the quality benefit category, alternatives IB and IIB, are also relatively expensive in comparison to the other alternatives. However, alternatives IA and IIA perform well in this benefit and rank highly in terms of discounted total cost. If quality is the only benefit considered, alternative IA maintains the smallest cost-benefit ratio. Figure 12 shows the resulting cost-benefit ratios when quality is the sole benefit considered. Alternative IVA maintains third position despite a relatively weak score in quality. This is due to the low discounted total cost of alternative IVA.

When Command Opportunity is the only benefit considered, the ranking of preferred alternatives changes, as seen in Figure 13. In this case, alternative IIIA possesses the smallest cost-benefit ratio, followed by IA, IVA, and then IIA. This is a unique circumstance caused by alternative IIIA possessing the highest score in this benefit. Recall from Table 4 that alternatives IA and IIA are at or near the top in every benefit category with the exception of Command Opportunity. Combined with the low discounted total cost of alternative IIIA, consideration of Command Opportunity alone causes alternative IIIA to become the most preferred alternative. However, consideration of more than one benefit nearly always favors alternatives IA and IIA.

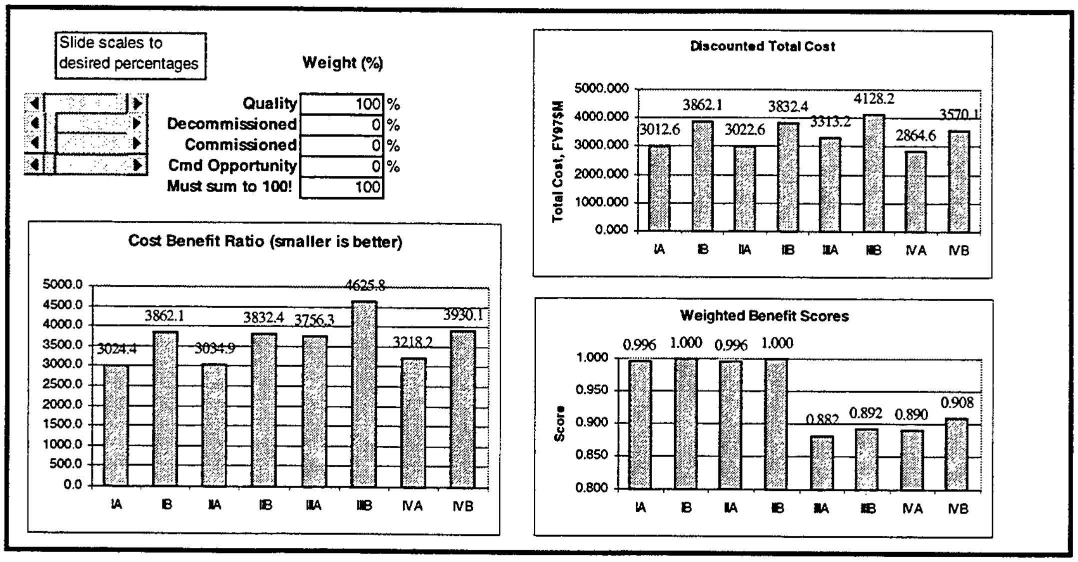

Figure 12: Additive Weighting and Scaling Model with Quality as the only Benefit Considered

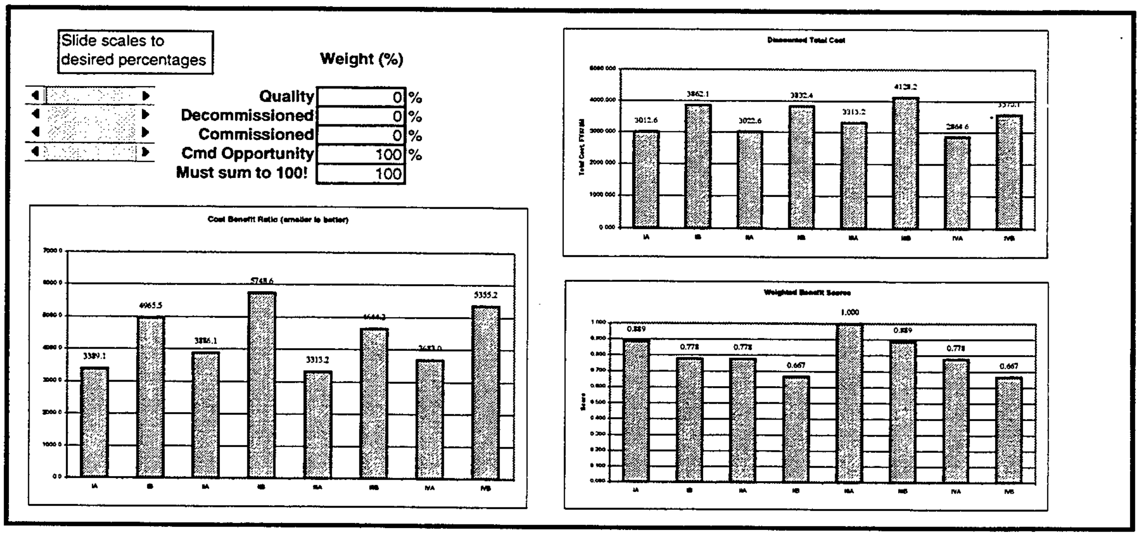

Figure 13: Additive Weighting and Scaling Model with Command Opportunity as the only Benefit Considered

B. HIERARCHICAL MULTI-ATTRIBUTE MODEL

1. Definition

The second cost-benefit analysis method employed is a hierarchical multi-attribute model (Marshall, 1995). Similar to the Additive Weighting and Scaling model,

this model allows user-defined priorities to be placed upon benefits at the user's discretion. However, this model also allows the user to weigh the importance of cost relative to benefit. Conditional probability is then used to determine the final weights assigned to each attribute. This model is especially appropriate when decisions are driven by costs and decision-makers desire an ability to weigh the importance of cost relative to benefit.

The decision-maker is now tasked with prioritizing costs as well as benefits. This approach leads the decision-maker to an overall value score for each alternative j, V_j., in units of cost. This overall score is obtained for each alternative j by determining V_C and V_B, the equivalent cost and benefit scores and combining them to yield V_j. Specifics of this model are shown in Appendix A.

2. Results

The results of the hierarchical multi-attribute model are consistent with those of the additive weighting and scaling model. Alternatives IA, IIA, and IVA maintain their dominance over the other five alternatives. Figure 14 shows the results with each benefit being weighed equally. In this case, alternative IA is preferred until the weight placed upon cost, π_C , exceeds 0.93, at which point alternative IVA becomes more attractive. If all weight is placed on cost (i.e. π_C equals 1.00, see Appendix A), then the least expensive alternative is preferred. However, alternatives IA and IIA are not much more expensive and both possess much greater benefit potential than IVA. Consequently, the more weight placed on benefit as opposed to cost, the more attractive IA and IIA become and the less attractive IVA becomes.

If Command Opportunity is the only benefit considered, then alternative IIIA warrants some consideration, as shown in Figure 15. If the emphasis placed upon cost is less than 0.59, then alternative IIIA is now the preferred alternative. If cost is weighed between 0.59 and 0.87, then alternative IA is preferred, else alternative IVA again comes out on top when the weight given to cost is more than 0.87.

Preferred Alternative	IA		IVA	
Weight Assigned to Cost π_c	0	0.93		1

Figure 14: Preferred Alternative Based Upon π_C and Considering All Benefits Equally

Preferred Alternative	IIIA		IA		IVA	
Weight Assigned to Cost π_c	0	0.59		0.87		1

Figure 15: Preferred Alternative Based Upon π_C and Considering Command Opportunity Alone

Alternative IA dominates the remaining alternatives if any of the remaining three benefits are given 1.0 relative weight. The results of giving 100% of the weight to quality, number of squadrons decommissioned, and number of squadrons commissioned are shown in Figures 16, 17, and 18, respectively. As shown, alternative IA is preferred until cost becomes of overwhelming importance. If cost is the major consideration, then alternative IVA becomes the preferred alternative.

Preferred Alternative	IA		IVA	
Weight Assigned to Cost π_c	0	0.93		1

Figure 16: Preferred Alternative Based Upon π_C and Considering Quality Alone

Preferred Alternative	IA		IVA	
Weight Assigned to Cost π_c	0	0.94		1

Figure 17: Preferred Alternative Based Upon π_C and Considering Number of Squadrons Decommissioned Alone

Preferred Alternative	IA		IVA
Weight Assigned to Cost π_c	0	0.92	1

Figure 18: Preferred Alternative Based Upon π_C and Considering Number of Squadrons Commissioned Alone

VI. SENSITIVITY ANALYSIS

A. INTRODUCTION

The results generated by these two models rely heavily on the accuracy of the input data. Sensitivity analysis is warranted to determine if slight changes in any of the inputs alter the results. If a slight change in an input changes the ranking of the alternatives, then that input is 'sensitive'. An input that may be altered at will without affecting the resulting ranking of the alternatives is 'insensitive'.

Inputs to the two models used may be broken down into three major categories: external, historical, and original. External inputs are those given by another organization as factual. In this case, the external input is student throughput, which was determined by N889, and is treated as a fixed input. Historical inputs obviously refer to those determined by analysis of historical data. The costs per flight hour used in our models are examples of historical data. They are estimates based upon analogous systems, namely the SH-60B and the HH-60H. Estimating the costs per flight hour of the CH-60S and SH-60R with historical costs of the HH-60H and SH-60B may not be completely accurate. Therefore, sensitivity analysis is warranted on the costs per flight hour used in this study. The final category of input may be viewed as original. These inputs were created from scratch and based upon related research and hard work. Original inputs in the two models considered are the numbers of flights required and the maintenance reliability rates associated with each of the various flight syllabi for each alternative. Again, sensitivity analysis is warranted in this case, as well.

B. COST PER FLIGHT HOUR

As discussed previously, the costs per flight hour are generated using the VAMOSC database for historical operating and support costs. Historical data for the HH-60H is considered representative of the costs that may be incurred for the CH-60S. In a similar fashion, historical costs of the SH-60B are used as a basis for the SH-60R. The HH-60H and SH-60B costs are used because of the similarities in airframe and missions with the CH-60S and SH-60R, respectively.

The H-60 airframe is reliable and many lessons have been learned from previous variants of the H-60. In fact, it may be possible, over time, to reduce the cost per flight hour below that currently experienced by the H-60. On the other hand, it is also possible that the cost per flight hour would increase due to such factors as lack of availability of parts. We now consider the impact of a 25% reduction in the cost per flight hour on the resulting ranking of alternatives, as shown in Table 6.

Helicopter	Baseline Cost per Flight Hour	Reduced Cost per Flight Hour
CH-60S	3553	2665
SH-60R	3745	2809

Table 6: Baseline and Reduced Costs per Flight Hour (FY97$)

Reducing the cost per flight hour has no effect on procurement costs or any of the benefits. The only affected attribute is annual operating cost. Table 7 shows the effects of a 25% reduction in cost per flight hour on discounted total cost. Figure 19 shows the same results graphically. The reduction in annual operating costs is evident. Note that alternative IVA continues to be the least expensive, but alternative IIA overtakes IA to assume second place. This exchange is due to the high cost per flight hour of the MH-53 ($7119 (FY97)). Recall that the MH-53 is flown in alternative I but is replaced by the CH-60 in alternative II. The estimated cost per flight hour of the CH-60, $3553 (FY97), is already half that of the MH-53. Reducing the flight hour cost of the CH-60 by another 25% serves to widen this gap, making operating the CH-60S far less expensive than flying the MH-53. However, the resulting difference in discounted total cost between these two alternatives is minimal. Since the raw benefit scores of alternative IA are better than those of alternative IIA *in every benefit*, alternative IA still maintains dominance over IIA in all cases in terms of the cost-benefit ratio. Since their respective discounted total costs are nearly identical, there is no instance when alternative IIA is preferred over alternative IA.

	Discounted Total Cost		
Alternative	**Baseline (FY97$M)**	**Reduced(FY97$M)**	**% Reduction**
IA	3013	2630	12.7
IB	3862	3317	14.1
IIA	3023	2628	13.0
IIB	3832	3260	14.9
IIIA	3313	2899	12.5
IIIB	4128	3553	13.9
IVA	2865	2533	11.6
IVB	3570	3084	13.6

Table 7: Effects of a 25% Reduction in Cost per Flight Hour

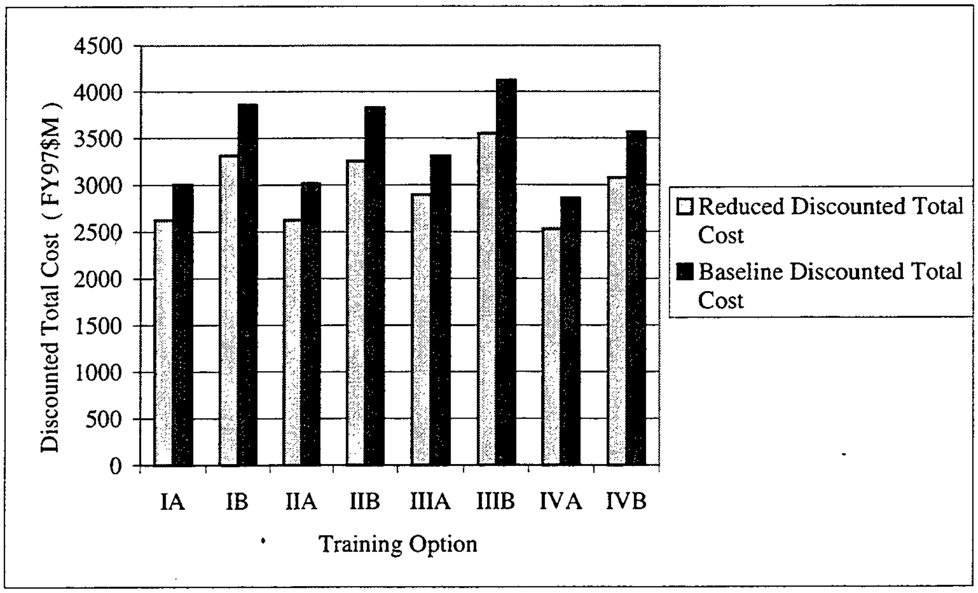

Figure 19: Discounted Total Cost Comparision Between Baseline and Reduced Flight Hour Costs

It is worth noting, however, that alternative IIIA is preferred in one instance. Alternative IIIA outscores the other alternatives in the Command Opportunity benefit. Its discounted total cost places fourth out of the eight alternatives. If the decision-maker considers Command Opportunity alone and uses the hierarchical multi-attribute model, then alternative IIIA is preferred for values of π_C less than 0.61. If π_C is between 0.61 and 0.86, then alternative IA is preferred, and if π_C exceeds 0.86 then alternative IVA becomes the alternative of choice. In other words, if cost is not a major concern and Command

Opportunity is the only benefit worth considering, then alternative IIIA has merit and deserves consideration, as seen in Figure 20.

Preferred Alternative		IIIA		IA		IVA	
Weight Assigned to Cost π_C	0		0.61		0.86		1

Figure 20: Preferred Alternative Based Upon π_C and Considering Command Opportunity Alone Using Reduced Cost Per Flight Hour

Independent of the particular weights assigned to each benefit, alternatives IA and IIA consistently perform well. Alternative IVA becomes more attractive as cost becomes of greater concern.

In a similar fashion, the effects of increasing the cost per flight hour by 25 percent are now analyzed. The resulting values are shown in Table 8 and displayed in Figure 21.

Increasing the cost per flight hour does not affect the procurement costs or any of the benefit scores. The sole attribute affected by increasing the cost per flight hour is annual operating costs. A comparison of the baseline and increased discounted total costs is presented in Table 9. Each alternative experiences an increase in discounted total cost due to increasing annual operating costs. Note that the relative positioning of the alternatives remains unchanged.

Helicopter	Baseline Cost per Flight Hour	Increased Cost per Flight Hour
CH-60S	3553	4441
SH-60R	3745	4681

Table 8: Baseline and Increased Costs per Flight Hour (FY97$)

	Discounted Total Cost		
Alternative	Baseline (FY97$M)	Increased(FY97$M)	% Increase
IA	3013	3396	12.7
IB	3862	4407	14.1
IIA	3023	3417	13.0
IIB	3832	4405	14.9
IIIA	3313	3727	12.5
IIIB	4128	4703	13.9
IVA	2865	3196	11.6
IVB	3570	4056	13.6

Table 9: Effects of a 25% Increase in Cost per Flight Hour

Alternative IVA remains least expensive and alternative IA maintains second position. Previously, the advantages that alternative IA had over alternative IIA stemmed from the fact that IA did not require procurement of any CH-60S helicopters to replace the MH-53. The only cost advantage that alternative IIA had over IA was the fact that the CH-60S is expected to cost less to operate per flight hour. Increasing the cost per flight hour of the CH-60S reduces the one advantage that alternative IIA had over IA. This allows alternative IA to maintain its hold on second position. Note, however, that alternative IIA is a close third. The most attractive alternatives continue to be IA, IIA, and IVA.

Alternative IA consistently possesses the best cost / benefit ratio and dominates the other alternatives in all but one instance. If command opportunity is the sole benefit considered and the hierarchical model is chosen, then alternative IIIA warrants consideration for π_c values less than 0.51, as seen in Figure 22. If the weight placed on cost is greater than 0.51, or if any other combination of benefits is considered, then alternative IA is preferred.

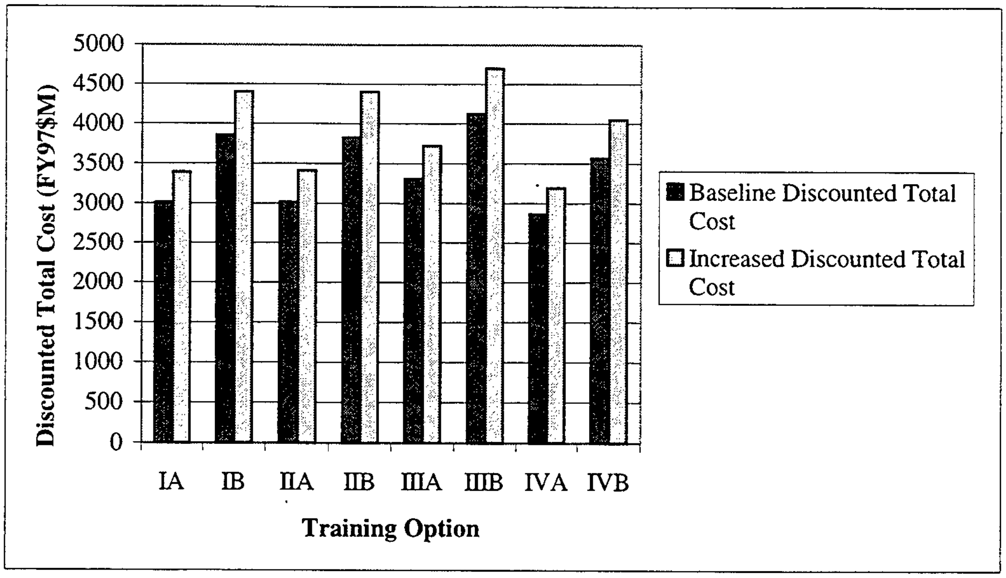

Figure 21: Discounted Total Cost Comparision Between Baseline and Increased Flight Hour Costs

Preferred Alternative	IA		IVA
Weight Assigned to Cost π_C	0	0.51	1

Figure 22: Preferred Alternative Based Upon π_C and Considering Command Opportunity Alone Using Increased Cost Per Flight Hour Values

C. SYLLABUS CHARACTERISTICS

1. Syllabus Flight Hours

The number of flight hours expected in each syllabus may be optimistic. We consider the impact of an increase of 25% in H-60 syllabus length. The length of the TH-57B/C syllabi remain unchanged. The costs per flight hour values are set equal to the values determined through VAMOSC analysis: $ 3553 (FY97) per flight hour for the CH-60S and $ 3745 (FY97$) per flight hour for the SH-60R.

Increasing the syllabus length increases both the procurement costs and the annual operating costs for each alternative. The reason for higher procurement costs is that maintaining a constant student throughput while increasing the number of flight hours required causes the resulting number of required helicopters to increase. Additionally,

flying the aircraft for a greater number of flight hours annually obviously increases the annual operating costs.

The increase in procurement cost and 20 year discounted total annual operating costs for each alternative are shown in Table 10.

Alt	Baseline Procurement Cost (FY97$M)	Increased Procurement Cost (FY97$M)	% Δ	Baseline Discounted Annual Cost (FY97$M)	Alternative Discounted Annual Cost (FY97$M)	% Δ
IA	1113	1203	8.1	1899	2282	20.1
IB	1366	1507	10.3	2496	3097	24.1
IIA	1168	1257	7.6	1855	2249	21.2
IIB	1448	1589	9.7	2385	2958	24.0
IIIA	1380	1496	8.4	1934	2347	21.4
IIIB	1735	1871	7.8	2394	2968	24.0
IVA	1261	1367	8.4	1604	1935	20.6
IVB	1533	1680	9.6	2037	2523	23.9

Table 10: Effects of Increasing Syllabus Length by 25% on Procurement and Annual Operating Costs

As expected, increasing the number of flight hours required in the flight training syllabus drastically affects the annual operating costs for each alternative. The procurement costs are affected as well, but to a lesser degree. The effects of this increase on the selection of the preferred alternative are now examined. The resulting discounted total cost for each of the alternatives is shown in Figure 23.

Alternative IA continues to be preferred over all but the most unrealistic benefit weighting combinations. As in the previous example, alternative IIIA deserves consideration if the decision-maker is concerned primarily with Command Opportunity (i.e. >92% weighting). In this case, alternative IIIA is preferred for $\pi_c < 0.57$, alternative IA is preferred for $0.57 < \pi_c < 0.93$, and alternative IVA is preferred for $\pi_c > 0.93$. Figure 24 shows this situation. Other combinations of benefit weighting result in alternative IA being preferred.

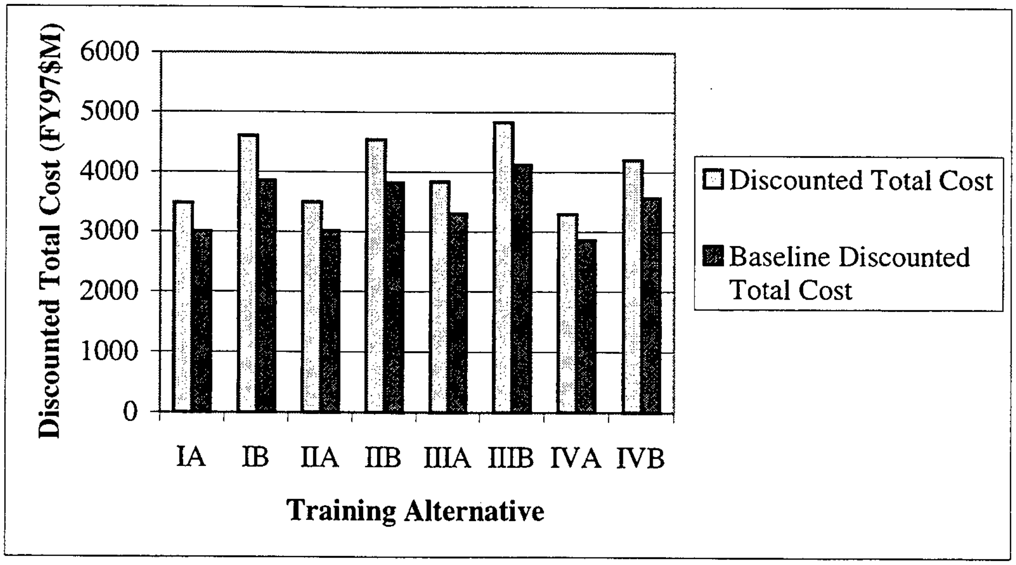

Figure 23: Comparison of Discounted Total Costs Between Baseline and Increase in Syllabus Flight Hours

Preferred Alternative		IIIA		IA		IVA	
Weight Assigned to Cost π_C	0		0.57		0.93		1

Figure 24: Preferred Alternative Based Upon π_C and Considering Command Opportunity Alone and Increasing Syllabus Flight Hours by 25%

2. Maintenance FMC / MC Rates

The final inputs considered for sensitivity analysis are the Full Mission Capable, or FMC, rates and the Mission Capable, or MC, rates. These values represent the probability that a given helicopter on a given day is classified FMC or MC. An FMC aircraft is one in which all systems and mission related equipment are in full working order, and is therefore able to conduct all missions for which it is designed. An MC aircraft, by contrast, is one that is able to perform some, but not all, of its designed missions. Some training flights require an FMC aircraft in order to successfully complete required maneuvers, while other flights may be able to use an MC aircraft. The estimated values of FMC / MC percentages are important components in determining the number of helicopters required. High values of these rates reflect high readiness and good aircraft availability, which translates into

fewer aircraft needed. However, poor values demand a greater number of helicopters in order to meet the student demands. Historical values for the SH-60F/B are 42.7% FMC and 57.5% MC. It is possible that these values are pessimistic for the new CH-60S and SH-60R. The estimates used in this thesis are an FMC rate equal to 0.50 and an MC rate equal to 0.70 (Mullarky 1998). We now consider these 'baseline' rates ± 18% for sensitivity analysis. This range is chosen to ensure consideration of the current FMC and MC rates of 0.42 and 0.575, while also exploring the effects of potential FMC and MC rates of 0.68 and 0.88.

The first pair of rates considered is pessimistic, 0.42 FMC and 0.52 MC. These rates are close to the historical values of 42.7% and 57.5%. Since these rates reflect a poorer level of helicopter maintenance than the baseline values of 0.50 and 0.70, an increased number of helicopters required is anticipated in this case. Procurement cost is the only attribute affected by this change.

The second pair of maintenance rates addressed consists of an FMC rate of 0.68 and an MC rate of 0.88. These two values imply very strong maintenance practices resulting in fewer helicopters required to meet student throughput demands. Table 11 and Figure 25 show the respective changes in discounted total cost between the three cases.

While alternative IVA retains the smallest discounted total cost in every case, if the FMC / MC rates see an 18% improvement, alternative IIA overtakes alternative IA in terms of discounted total cost, as seen in Table 11. An 18% reduction in FMC / MC rates returns the baseline ordering of discounted total costs, with the best three alternatives being IVA, IA, and IIA.

Alternative	Baseline (FY97$M)	18% Increase in FMC/MC Rates (FY97$M)	18% Reduction in FMC/MC Rates (FY97$M)
IA	3013	2749	3675
IB	3862	3585	4731
IIA	3023	2746	3712
IIB	3832	3528	4742
IIIA	3313	3017	4152
IIIB	4128	3748	5187
IVA	2865	2563	3615
IVB	3570	3228	4511

Table 11: Comparison of Discounted Total Costs of Baseline, 18% Increase, and 18% Reduction in FMC and MC Rates

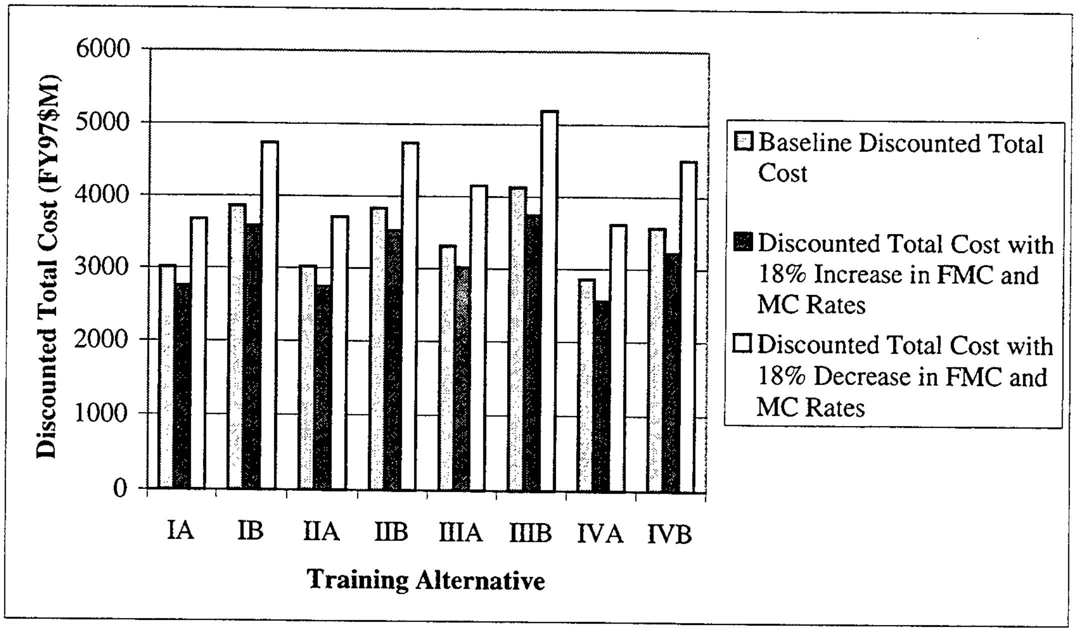

Figure 25: Comparison of Discounted Total Costs Between Baseline, 18% Increase and 18% Reduction in FMC and MC Rates

Altering the FMC and MC rates changes the number of aircraft procured in each alternative. However, these changes do not result in the selection of a different alternative. If every benefit is given some weight the preferred alternative is consistently alternative IA, followed closely by alternative IIA. However, as seen earlier, alternative IVA becomes the alternative of choice if nearly all emphasis is placed upon cost. If Command Opportunity is the only benefit considered, the preferred alternatives when increasing and decreasing the FMC / MC rates are shown in Figures 26 and 27, respectively.

Preferred Alternative		IIIA		IA		IVA	
Weight Assigned to Cost π_c	0		0.57		0.87		1

Figure 26: Preferred Alternative Based Upon π_C, Considering Command Opportunity Alone, and Increasing FMC / MC Rates by 18%

Preferred Alternative		IIIA		IA		IVA	
Weight Assigned to Cost π_c	0		0.59		0.88		1

Figure 27: Preferred Alternative Based Upon π_C , Considering Command Opportunity Alone, and Decreasing FMC / MC Rates by 18%

Conducting sensitivity analysis on cost per flight hour, syllabus length, and FMC/MC maintenance rates shed some light on the effects of these inputs upon the final determination of the preferred alternative. However, varying these inputs rarely affected the result. The only instances having different results from the baseline are those in which Command Opportunity receives 100% of the benefit weighting. We also note that alternative IVA starts becoming viable only if cost is of primary concern with π_c exceeding approximately 0.93. All combinations that assign some weight to every attribute result in alternative IA being preferred. Alternative IIA is nearly always second, with alternative IVA being preferred if cost is the main concern.

D. SENSITIVITY ANALYSIS CONCLUSIONS

Sensitivity analysis of cost per flight hour, syllabus length, and FMC/MC rates shows that our initial results are robust and do not dramatically change with significant changes in these inputs. Altering these inputs may have changed some of the attributes, such as procurement cost, but did not result in dramatic changes of the preferred alternative. Alternative IA continues to be the alternative of choice, unless extreme selections of cost and benefit weights are chosen. If π_c is less than approximately 0.55 and Command Opportunity is the only benefit of concern, then alternative IIIA deserves consideration. If cost is the major driver of the decision, with π_c greater than about 0.93, then alternative IVA warrants consideration. All other combinations of cost and benefit weighting yields results that point to alternative IA as the best, in terms of smallest cost-benefit ratio or equivalent value. Alternative IIA consistently places a close second to alternative IA. Alternative IVA becomes more attractive as the importance of cost versus benefit increases. All of the inputs considered in this sensitivity analysis are classified as

relatively insensitive. Ranking the alternatives IA, IIA and then IVA is reasonable and fits nearly all of the possible weighting combinations.

VII. CONCLUSIONS

The fruition of the Helicopter Master Plan requires addressing several key issues, one of which is how to restructure helicopter undergraduate flight training. Further, if restructuring is, in fact, desired, how should this be accomplished to maximize efficiency? These questions are addressed in this thesis using two cost-benefit models. The first is known as the Additive Weighting and Scaling model and the second as a Hierarchical Multi-attribute model. Both models consider four primary benefits and allows the decision-maker to weigh these benefits against one another as he or she desires. The difference in the two models is seen in how they handle costs. The Additive Weighting and Scaling model uses the total discounted total cost of each alternative in determining its cost-benefit ratio. The Hierarchical Multi-attribute model allows the decision-maker to additionally weigh cost against the benefits, thereby indicating how important cost is to the decision making process. Despite the differing approaches to the problem, these two methods provide consistent results.

Three alternatives stood apart from the rest: alternatives IA, IIA and IVA. Alternatives IA and IIA are very similar in make-up, the only difference being the type of helicopter which flies the AMCM mission. Alternative IA keeps the MH-53 helicopter in this role, while alternative IIA replaces the MH-53 with the CH-60. It is important to note that the selection of alternative IA or IIA will be made by flight testing of the CH-60S in the AMCM role. This testing is scheduled to occur in the Spring of 1999. If the CH-60S is found capable of performing the mission, then the MH-53 will be replaced by the CH-60S. As a consequence, alternative IA would no longer be feasible. If the MH-53 remains, then alternative IIA would be no longer feasible. The fact that alternatives IA and IIA are mutually exclusive is very important in interpreting the results of this analysis.

The results of both methods show that if each benefit receives some weight and cost is not of overwhelming importance (greater than or equal to approximately 90 %), then the preferred alternative is IA followed closely by IIA. If cost is extremely important, then alternative IVA deserves consideration. If Command Opportunity is the only benefit considered and cost is not very important (less than or equal to

approximately 60%), then alternative IIIA warrants consideration. Sensitivity analysis shows that changes in some key assumptions have no real effect on the resulting order of preferred alternatives. *The bottom line of this analysis is that, in most reasonable circumstances, alternative IA is preferred, followed by alternative IIA.*

The fact that alternatives IA and IIA are mutually exclusive *and* rank first and second in terms of preference solidifies the fact that maintaining the squadron organization as it is and replacing the current helicopters with the SH-60R or CH-60S, as appropriate, is the proper choice. The outcome of the current flight testing to determine the suitability of the CH-60S for the MH-53 mission has no bearing on the results of this analysis. If the MH-53 maintains its place in the Navy helicopter inventory, then alternative IA is preferred. Otherwise, alternative IIA is the alternative of choice.

There is potential for further research as a result of this analysis. Consideration of manpower requirements for instructors as well as maintenance personnel and support staff for each alternative could be considered. Also, costs for decommissioning and commissioning squadrons could also be added to both models, increasing the fidelity and producing more accurate results.

APPENDIX A: HIERARCHICAL MULTI-ATTRIBUTE MODEL FORMULATION

This model follows the formulation presented in Decision Making and Forecasting (Marshall 1995). We maintain the same notation. The alternatives and attributes are denoted by j and k, respectively. The raw score of alternative j in attribute k is represented with $r_{j,k}$. However, the attributes are now separated into two distinct groups, Cost, denoted with a subscript C, and Benefit, denoted with a subscript B. For example, if $\boldsymbol{r}$ represents the raw score vector of a particular alternative, then $\boldsymbol{r}$ may be partitioned into a cost component and a benefit component.

$$\boldsymbol{r} = (\boldsymbol{r}_C, \boldsymbol{r}_B)$$

Within each component, an attribute is chosen as a baseline. The units of the other attributes of that respective component are then converted into equivalent units of the chosen baseline. In this particular case, procurement cost and quality are chosen as the baselines for the cost and benefit components, respectively. A vector of 'equivalent weights', $\boldsymbol{w}$, is now constructed using the raw data and the selected baseline attributes.

To assist in determining this vector of equivalent weights, a 'best' and 'worst' score for each attribute is determined. Let $\overline{r}_k$ represent the best raw score, over all alternatives, of attribute k. Similarly, let $\underline{r}_k$ represent the worst raw score for attribute k. Therefore,

$$\overline{r} = (\overline{r}_1, \overline{r}_2, \overline{r}_3, \overline{r}_4, \overline{r}_5, \overline{r}_6) \text{ and } \underline{r} = (\underline{r}_1, \underline{r}_2, \underline{r}_3, \underline{r}_4, \underline{r}_5, \underline{r}_6)$$

The difference between these two vectors is used to create a new vector, Δ. This new vector represents the changes that must occur in each attribute to improve from the worst level to the best.

$$\Delta = \overline{r} - \underline{r}$$

The final piece required in determining trade-off weights is understanding the priorities assigned to each attribute and how they are linked by the laws of conditional probability. In this model, the decision-maker chooses the fractional weight that he or she wishes to assign to cost. This value is referred to as π_C. Consequently, the weight attributed to the benefits, as a whole, is equal to $(1 - \pi_C)$. Let π_q, π_d, π_{cm}, π_{co} refer to the

fractional weights of quality, number of squadrons decommissioned, number of squadrons commissioned, and command opportunity, respectively. These values are uniquely determined by the decision-maker, according to his or her personal preferences. This is done using the best 'guess' based on the feeling of the decision-maker or by treating the decision as a game considering risk (Marshall, 1995).

Procurement cost and Annual costs are both equally weighted in this model, i.e. each receives one half of the weight assigned to the cost partition. The final weights assigned to each benefit are equal to the user-defined weight conditioned upon the weight of benefits, as a whole. This determination of the final 'indifference probability' is depicted in Figure A-1. The shaded areas in Figure A-1 represent values directly determined by the decision-maker.

The equivalent value of each training alternative is determined by determining the equivalent value of the cost and benefit components separately and then combining them to determine the overall equivalent value of that particular alternative. The equivalent value of a particular alternative j, V_j, is determined as follows:

$$V_j = V_j(\boldsymbol{w}, \boldsymbol{r}) = V_{C,j}(\boldsymbol{w}_C, \boldsymbol{r}_C) + w_{C,B}\, V_{B,j}(\boldsymbol{w}_B, \boldsymbol{r}_B)$$

Where

$$V_C(\boldsymbol{w}_C, \boldsymbol{r}_C) = w_{C,1}\, r_{C,1} + w_{C,2}\, r_{C,2}$$

$$V_B(\boldsymbol{w}_B, \boldsymbol{r}_B) = w_{B,1}\, r_{B,1} + w_{B,2}\, r_{B,2} + w_{B,3}\, r_{B,3} + w_{B,4}\, r_{B,4}$$

$$w_{C,k} = \frac{\Delta_{C,1}\pi_{C,k}}{\Delta_{C,k}\pi_{C,1}}$$

$$w_{B,k} = \frac{\Delta_{B,1}\pi_{B,k}}{\Delta_{B,k}\pi_{B,1}}$$

$$w_{C,B} = \frac{\left(\overline{v}_C - \underline{v_C}\right)}{\left(\overline{v}_B - \underline{v_B}\right)} \frac{(1-\pi_C)}{\pi_C}$$

The first term in the numerator represents the difference between the best, or least expensive, alternative and the worst, or most expensive, alternative. The first term in the denominator is the same expression considering the benefits, rather than costs. Figure A-2 shows the resulting curves, each representing a given alternative. For a specific π_C, the alternative with the smallest equivalent value is preferred.

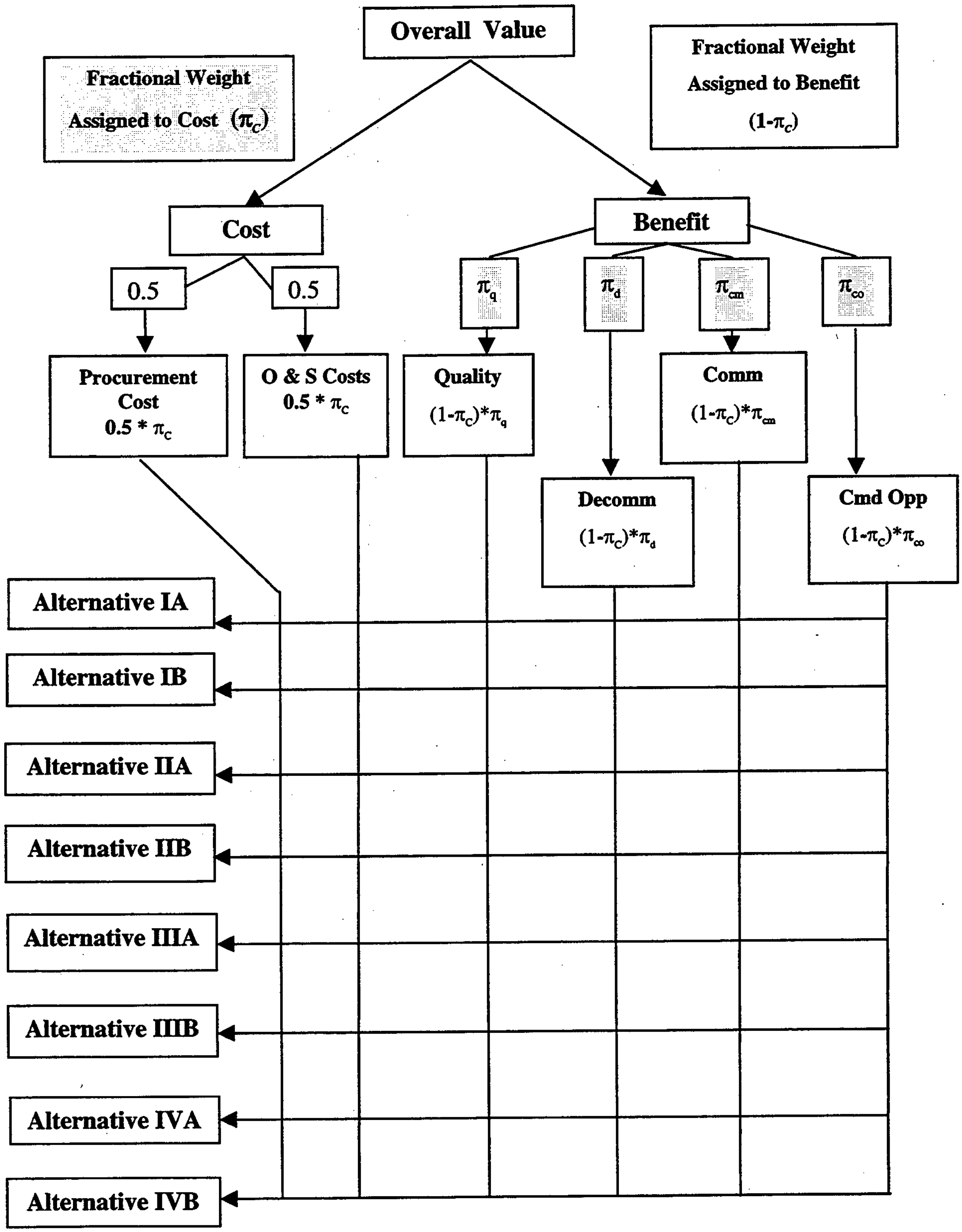

Figure A-1: Determination of Fractional Weights for each Attribute

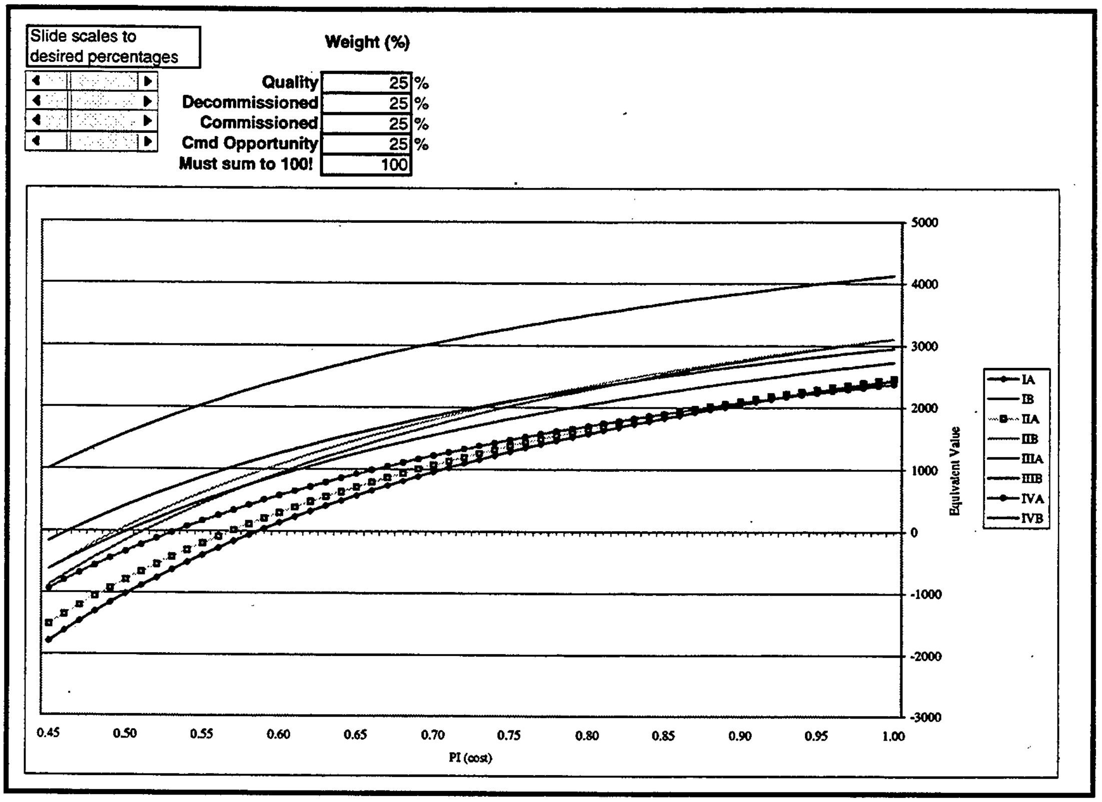

Figure A-2: Hierarchical Multi-attribute Model Results with Each Benefit Receiving Equal Wight

APPENDIX B: AIRCRAFT REQUIREMENT FORMULATION

The algorithm used to determine the number of aircraft required for a specific squadron is presented here. This algorithm was presented at the FRS Production Planning Factors Conference at the Bureau of Personnel (BUPERS) during the summer of 1998. This is the same algorithm used to calculate the number of helicopters required for each of the alternatives presented.

<u>Data Required</u> (historic, calculated or estimated)

- Total Annual CAT I equivalent throughput (ATR)
  Self-explanatory
- Historic FMC Rate (% FMC)
- Historic MC Rate (% MC)
  Historic Fully Mission Capable (FMC) / Mission Capable (MC) rate. An FMC aircraft is capable of immediately conducting any mission for which the helicopter is designed. A MC aircraft is capable of performing some, but not all, of the designed missions. Historically, the CNAP FMC/MC average for the H-60B/F FRS is 42.5/57.5. In this study, values of 0.50/0.70 are used instead of the historical data, due to the increased reliability expected from the CH-60S and SH-60R.
- TAT (Maintenance turn-around time allowance, in hours)
  Maintenance time required between flights for daily/turnaround inspections. In this study, 2 hours is used.
- SYL-HRS (syllabus hours)
  The number of flight hours required to complete the training syllabus. This value does not include functional check flights, warm-ups or ferry flights.
- SYL-OVHD (syllabus overhead hours)
- OTH-OVHD (other overhead hours, total per student)
- TOT-HRS (total annual flight hours required)
  The sum of syllabus hours, syllabus overhead hours, and other overhead hours.

- SYL-EVT (syllabus sorties)

  The number of scheduled flight events in the respective training syllabus. Does not include ground training or simulator flights.

- SYL-FMC (number or percent syllabus sorties requiring FMC aircraft)
- SYL-MC (number or percent syllabus sorties requiring MC aircraft)
- FLYDAYS (training/flying days per year)
- SORTIE-LGTH (average sortie length)
- SCT (required instructor-student contact time per sortie)
- EI (efficiency index)
- CX-WX (percent of sorties cancelled due to weather)
- UTE-WSPD (WSPD planned utilization rate, in hours/year)
- ACDAY (aircraft flying day, in hours)

Calculation of Required Ready for Training (RFT) rate

1. Determine percent of sorties requiring FMC aircraft

   Number of sorties requiring FMC / Total syllabus sorties = % sortie FMC

2. Determine percent of sorties requiring MC aircraft

   Number of sorties requiring MC / Total syllabus sorties = % sortie MC

3. Determine required RFT rate

   % sorties FMC * historic FMC rate + % sorties MC * historic MC rate = RFT rate

Annual Individual Aircraft Utilization Formula

1. Define maximum available sorties per day per aircraft

   Aircraft flying day / (average sortie length + TAT) = Max sorties per day per aircraft

2. Define planned max available flight per day per aircraft

   Planned max sorties per day per aircraft * average sortie length

   = Planned max available flight time per day per aircraft

3. Define max flight hours per year per aircraft

   Max available flight time per day per aircraft * training days per year

   = Max flight hours per year per aircraft

4. Adjust Step 3 for Wx impact

   Max flight hours per year * (1 - %Wx cancellation) = Wx adjusted flight hours

5. Adjust for scheduling efficiency

   Wx adjusted flight hours * EI = Efficiency adjusted flight hours

6. Adjust for estimated RFT availability

   Efficiency adjusted flight hours * RFT rate = planned aircraft annual utilization

<u>Calculate Required Aircraft</u> (Number of aircraft to achieve Required Training Rate with the Planned Utilization)

1. Determine required number of aircraft

   Total flight hours required / planned aircraft annual utilization

   = number of aircraft required

APPENDIX C: ALTERNATIVE SYLLABUS PRESENTATION

Alternative I

Plan A

Current Squadron	**Proposed Squadron**	**Student Throughput**	**Description of Changes**
HS-10	HS-10	60 – 60R 63 – 60S	Replace current inventory with 5 CH-60S and 11 SH-60R helicopters. All training except CSAR / NVG flights will be conducted in the SH-60R.
HC-3	HC-3	74	Replace current inventory with 11 CH-60S helicopters.
HSL-41	HSL-41	94	Replace current inventory with 17 SH-60R helicopters.
HSL-40	HSL-40	95	Replace current inventory with 17 SH-60R helicopters.
HC-2	HC-2	18	Replace current inventory with 3 CH-60S helicopters.
HMT-302	HMT-302	24	Keep current inventory of MH-53 helicopters

Plan B

Current Squadron	**Proposed Squadron**	**Student Throughput**	**Description of Changes**
HS-10	HS-10	53 – 60R 63 - 60S	Replace current inventory with 5 CH-60S and 14 SH-60R helicopters. All training except CSAR / NVG flights will be conducted in the SH-60R.
HC-3	HC-3	69	Replace current inventory with 16 CH-60S helicopters.
HSL-41	HSL-41	78	Replace current inventory with 20 SH-60R helicopters.
HSL-40	HSL-40	79	Replace current inventory with 20 SH-60R helicopters.
HC-2	HC-2	16	Replace current inventory with 4 CH-60S helicopters.
HMT-302	HMT-302	24	Keep current inventory of MH-53 helicopters

Alternative II

Plan A

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
HS-10	HS-10	60 – 60R 63 – 60S	Replace current inventory with 10 CH-60S and 11 SH-60R helicopters. All training except CSAR / NVG flights will be conducted in the SH-60R.
HC-3	HC-3	74	Replace current inventory with 11 CH-60S helicopters.
HSL-41	HSL-41	94	Replace current inventory with 17 SH-60R helicopters.
HSL-40	HSL-40	95	Replace current inventory with 17 SH-60R helicopters.
HC-2	HC-2	42	Replace current inventory with 7 CH-60S helicopters.
HMT-302	Decom	--	Decommission. Additional CH-60S requirement reflected in increased student throughput in HC-2.

Plan B

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
HS-10	HS-10	53 – 60R 63 – 60S	Replace current inventory with 15 CH-60S and 14 SH-60R helicopters. All training except CSAR / NVG flights will be conducted in the SH-60R.
HC-3	HC-3	69	Replace current inventory with 16 CH-60S helicopters.
HSL-41	HSL-41	78	Replace current inventory with 20 SH-60R helicopters.
HSL-40	HSL-40	79	Replace current inventory with 20 SH-60R helicopters.
HC-2	HC-2	40	Replace current inventory with 10 CH-60S helicopters.
HMT-302	Decom	--	Decommission. Additional CH-60 requirement reflected in increased student throughput in HC-2.

Alternative III

Plan A

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
CH-60 FRS (W)	HS-10	84	Replace current inventory with 3 CH-60S helicopters
CH-60 FRS (E)	Comm HS-1	38	Replace current inventory with 8 CH-60S helicopters.
SH-60 FRS (W)	HSL-41	123	Replace current inventory with 11 SH-60R helicopters.
SH-60 FRS (E)	HSL-40	125	Replace current inventory with 11 SH-60R helicopters.
CH-60 Tactics (W)	HC-3	68	Replace current inventory with 7 CH-60S helicopters.
CH-60 Tactics (E)	Comm	101	Commission squadron or expand WTU with 10 CH-60S helicopters.
SH-60 Tactics (W)	Comm	123	Commission squadron or expand WTU with 16 SH-60R helicopters.
SH-60 Tactics (E)	Comm	125	Commission squadron or expand WTU with 16 SH-60R helicopters.

Plan B

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
CH-60 FRS (W)	HS-10	35	Replace current inventory with 6 CH-60S helicopters
CH-60 FRS (E)	Comm HS-1	77	Replace current inventory with 13 CH-60S helicopters.
SH-60 FRS (W)	HSL-41	104	Replace current inventory with 17 SH-60R helicopters.
SH-60 FRS (E)	HSL-40	106	Replace current inventory with 18 SH-60R helicopters.
CH-60 Tactics (W)	HC-3	68	Replace current inventory with 7 CH-60S helicopters.
CH-60 Tactics (E)	Comm	101	Commission squadron or expand WTU with 10 CH-60S helicopters.
SH-60 Tactics (W)	Comm	123	Commission squadron or expand WTU with 16 SH-60R helicopters.
SH-60 Tactics (E)	Comm	125	Commission squadron or expand WTU with 16 SH-60R helicopters.

Alternative IV

Plan A

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
CH-60 FRS (W)	HS-10	163	Replace current inventory with 15 CH-60S helicopters.
CH-60 FRS (E)	Comm HS-1	217	Commission squadron with 19 CH-60S helicopters.
CH-60 Tactics (W)	HC-3	55	Replace current inventory with 5 CH-60S helicopters.
CH-60 Tactics (E)	Comm	56	Replace current inventory with 5 CH-60S helicopters.
SH-60 Tactics (W)	HSL-41	69	Replace current inventory with 9 SH-60R helicopters.
SH-60 Tactics (E)	HSL-40	69	Replace current inventory with 9 SH-60R helicopters.

Plan B

Current Squadron	Proposed Squadron	Student Throughput	Description of Changes
CH-60 FRS (W)	HS-10	140	Replace current inventory with 23 CH-60S helicopters.
CH-60 FRS (E)	Comm HS-1	186	Commission squadron with 31 CH-60S helicopters.
CH-60 Tactics (W)	HC-3	55	Replace current inventory with 5 CH-60S helicopters.
CH-60 Tactics (E)	Comm	56	Replace current inventory with 5 CH-60S helicopters.
SH-60 Tactics (W)	HSL-41	69	Replace current inventory with 9 SH-60R helicopters.
SH-60 Tactics (E)	HSL-40	69	Replace current inventory with 9 SH-60R helicopters.

APPENDIX D: DISCOUNTED TOTAL COST

Discounted Total Cost Determination **REAL DISCOUNT RATE = 0.035**

	ANNUAL COST							
	IA	IB	IIA	IIB	IIIA	IIIB	IVA	IVB
Annual Cost	133.626	175.626	130.503	167.795	136.047	168.359	112.843	143.349
Year								
0								
1	129.108	169.687	126.090	162.121	131.446	162.666	109.027	138.501
2	124.742	163.949	121.826	156.639	127.001	157.165	105.340	133.818
3	120.523	158.405	117.706	151.342	122.706	151.850	101.778	129.293
4	116.448	153.048	113.726	146.224	118.557	146.715	98.336	124.920
5	112.510	147.872	109.880	141.279	114.548	141.754	95.011	120.696
6	108.705	142.872	106.164	136.501	110.674	136.960	91.798	116.614
7	105.029	138.041	102.574	131.885	106.932	132.329	88.693	112.671
8	101.477	133.372	99.105	127.426	103.315	127.854	85.694	108.861
9	98.046	128.862	95.754	123.116	99.822	123.530	82.796	105.180
10	94.730	124.505	92.516	118.953	96.446	119.353	79.996	101.623
11	91.527	120.294	89.387	114.931	93.185	115.317	77.291	98.186
12	88.432	116.226	86.364	111.044	90.033	111.417	74.677	94.866
13	85.441	112.296	83.444	107.289	86.989	107.649	72.152	91.658
14	82.552	108.499	80.622	103.661	84.047	104.009	69.712	88.558
15	79.760	104.830	77.896	100.155	81.205	100.492	67.355	85.564
16	77.063	101.285	75.262	96.768	78.459	97.094	65.077	82.670
17	74.457	97.860	72.717	93.496	75.806	93.810	62.876	79.875
18	71.939	94.550	70.258	90.334	73.242	90.638	60.750	77.173
19	69.507	91.353	67.882	87.280	70.766	87.573	58.696	74.564
20	67.156	88.264	65.586	84.328	68.372	84.611	56.711	72.042
SUM	1899.153	2496.069	1854.756	2384.772	1933.552	2392.784	1603.766	2037.333
Procurement	1113.400	1366.000	1167.800	1447.600	1379.600	1735.400	1260.800	1532.800
Discounted Total Cost	3012.553	3862.069	3022.556	3832.372	3313.152	4128.184	2864.566	3570.133

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